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# An Exploratory Study of the Army-as-a-System Core Skills: Comparing the Effectiveness of Warfighting Tactics Using MANA

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**ABSTRACT**

The agent based distillation MANA was used for a parametric study of the seven core skills of the Army-as-a-system model, using a bottom-up approach. Simple tactics were developed, then combined, so more complex behaviour emerged. Scenarios in which base and combined tactics were played against each were used to measure the effectiveness of various combinations of core skills. Preliminary results indicate that the behaviour displayed by the simulation entities led to multiple distinct end-states. In addition, a 'rock-scissors-paper' paradigm emerged between combinations of tactics, where a cyclic, rather than linear, relationship was observed for the capacity of pairs of tactics to perform well against one another.

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# An Exploratory Study of the Army-as-a-System Core Skills: Comparing the Effectiveness of Warfighting Tactics Using MANA

## Executive Summary

Long term planning for the Army is inherently difficult due to the uncertain nature of future warfighting. This report presents a method for exploring warfighting at a generic level thus avoiding issues relating to context or equipment. It looks at concepts of warfighting through the use of the agent based distillation MANA that allows an abstract representation of conflict. The method used in this paper was to compare different tactics based on a previous model of warfare, whereby all actions are described in terms of a set of seven core skills (Engagement, Information Collection, Communication, Decision Making, Sustainment, Movement, Protection). In this paper we report the results obtained from this study and show the relative strengths and weaknesses of these tactics.

A set of eleven base tactics were derived that stressed one or more of each of these core skills. An example is "Sight En-Cluster-Attack" whereby once the enemy is sighted, the force will cluster very tightly and then advance in a controlled fashion to attack the enemy. This tactic stresses both good Information Collection and Movement. Another tactic is "Combat Advantage" whereby the force only attacks if it knows that it has a numerical advantage. This tactic stresses good Decision Making. Each of the eleven tactics was described in a semi-qualitative fashion in terms of the fraction of the core skill involved (where the sum added up to unity, eg engagement 0.5, movement 0.5). These tactics were played off against a defined default opposition force using the difference between blue and red casualties as the primary measure. In most cases, the raw capabilities of the forces (eg detection range, kill probability and movement rate) were kept constant.

Given these results, selected paired combinations of base tactics were examined. Again these were described in terms of the fraction of the core skill involved. These combined tactics were played against a default opposition force. A method was derived whereby the actual casualty differences were compared with the expected values from summing the individual capabilities of the base tactics. This allowed identification of synergisms or antagonisms. The most effective (synergistic) tactic involved a combination of the "Sight En-Envelopment" and "Slow down on contact" base tactics (described as movement 0.65, decision making 0.25, information collection 0.1). Stand out successful tactics tended to involve intelligent positioning of forces to inflict a large number of casualties on an onrushing enemy. Unsuccessful tactics were also analysed with a tactic based on "Combat advantage" and "Slow down on contact" being the poorest. It was interesting to note that tactics involving Movement and Decision Making appeared in both the best and worst performing lists and that skill in application of the forces is the important feature.

Comparison of the different combined tactics was then made through play-off of selected combined tactics against single tactics and also combined tactics against combined tactics. The results from these studies revealed various insights into relationships between the core skills. For instance, a tactic based on Engagement (0.35), Movement (0.5) and Protection (0.15) was seen to be powerful. There were inconsistencies however, and it is clear that no one combined tactic is to be preferred, at least not according to this study. A "rock-paper-scissors" relationship was found whereby a broad skill set beat tactics heavy in Engagement and Decision Making, which in turn beat Information Collection and Movement weighted tactics which beat the broad skill set.

Finally, we investigated the effect of a blockage on the battlefield, as one might find in urban warfare. Differences were found to the unencumbered battlefield; for instance, the Engagement, Movement and Protection tactic described in the previous paragraph was far less effective. In general, Movement and Information Collection were not so useful when the blockage was introduced. Two tactics were dominant, one based on Engagement (0.5) and Decision Making (0.5) and the other based on Engagement (0.35), Decision Making (0.5) and Protection (0.15).

This study has shown that MANA is a useful tool for comparing tactics based on the "Army-as-a-system" core skills. As with all agent based distillations the results are intended to show insights and trends rather than provide definitive and quantitative evidence for selecting specific force structures. As such, they play a critical role in "front-end studies", particularly in developing new concepts or exploring potential new contexts. Combined with other work using a top down variation of the input parameters, this allows initiation of new ideas of how to conduct future warfare. Such insights now need further examination using more manpower intensive tools such as conventional wargaming.

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# Glossary

**Acronyms**

| | |
|---|---|
| AAAS | Army-as-a-system |
| ABD | agent based distillation |
| Bt | base tactic |
| COM | communication |
| Ct | combined tactic |
| DM | decision making |
| DSTO | Defence Science and Technology Organisation |
| DTA | Defence Technology Agency |
| ENG | engagement |
| IC | information collection |
| ID | identification |
| LER | loss exchange ratio |
| MANA | Map Aware Non-uniform Automata |
| MOV | movement |
| PRO | protection |
| SUS | sustainment |

**Definitions**

**Agent based distillation**
A simulation tool where technical details of a force are abstracted to allow focus on the behavioural aspects of entities within the simulation.

**Base tactic** A simple tactic represented in MANA, which represents a force more proficient than normal in certain core skills.

**Blockage** Used in this study to describe obstacles placed on the terrain that block movement, shots and line of sight.

**Combination matrix**
The result of a mathematical method used to measure the synergy between pairs of core skills.

**Combined tactic** A direct combination of two base tactics, which represents a force more proficient than normal in the core skills extracted from the two base tactics.

**Core skill** A fundamental skill that all military forces possess some level of proficiency in. There are seven core skills defined by the Army-as-a-system framework.

**Countering graph** A visualisation tool used to show the relationships between sets of core skills based on scenario results.

**Linear effects** Defined as effects that are observed but predicted, and therefore of little interest.

**Playoff** Used by this study to describe scenarios where various base and combined tactics are fought against each other.

# 1. Introduction

Long-term planning for the Army is inherently difficult due to the uncertain nature of future warfighting. Force structures have enormous potential for change in the ten to twenty year timeframe. Because of this uncertainty, investigation within the long-term timeframe must be undertaken using a generic approach, using 'conceptual forces' instead of structuring them around present paradigms.

This approach can be facilitated by analysing the Army at a sufficiently generic level that uncertainties with respect to time are mitigated. In this study the capabilities of an army are broken down into a set of basic skills. Understanding the interplay and relationships between these skills can give insights into determining possible future directions. Similar work to this has been undertaken previously using a top down approach [1-3]. The skill basis chosen for this study was taken from the definitions provided by the Army-as-a-system (AAAS) study [4, 5], which defines a set of seven core skills that can describe a force's capabilities.

To explore this space, tools are required that possess a sufficient level of abstraction as to avoid being too prescriptive in terms of the systems they describe. In this study, the class of tools known as agent based distillations (ABD) is chosen. ABDs tend to concentrate on the behavioural aspects of a force, abstracting technical details, and have been used extensively [6, 7] for this purpose previously.

Using one such ABD, Map Aware Non-uniform Automata (MANA) [8], a set of simple tactics are built and related to the AAAS. These tactics are then combined and played off against each other in an attempt to find emergent features of the system. Using these features it is then possible to draw insights into the complex relationship between basic skills.

To start with, we discuss the ABD tool chosen for this analysis, and then describe development of the various scenarios created in this study, including base tactics, combinations of base tactics and playoffs between tactics. Then we present and discuss the results of playing off the combinations of the skills against one another. We conclude with some of the insights derived from this study along with discussion of the future directions for research in this area. In addition, an extensive set of Appendices detail raw results for all scenarios developed during this study and issues associated with the MANA software.

# 2. Tools and models for analysing AAAS core skills

## 2.1 Army-as-a-system Core Skills

The AAAS core skills have been well defined in previous publications [4, 5]. The AAAS core skills attempt to 'capture the essence of military operations' by defining broad skills that remain relevant regardless of how a force may be structured, now or in the future. In addition, it was intended to be sufficiently generic to adequately describe a force at any particular level of interest. The AAAS construct is built on the concept that combinations of seven distinct core skills (see Table 1) adequately describe a force structure through its capacity to perform functions and/or deliver effects.

*Table 1 - Core Skill Definitions [9]*

| Core Skill | Abbreviation | Description |
|---|---|---|
| Engagement | ENG | The advantageous use of military systems to acquire, select, target and employ firepower against enemy assets in order to render opposition system(s) ineffective. |
| Information Collection | IC | The identification and exploitation of information sources, in order to possess relevant, accessible and useable information on the battlespace. |
| Communication | COM | The establishment and utilisation of communications infrastructure in order to support effective, efficient and secure information transfer. |
| Decision Making | DM | The formulation of operational plans and responses based on the assimilation of current and past information in order to deliver timely, judicious and unambiguous commands to subordinates. |
| Sustainment | SUS | The maintenance of personnel and equipment at appropriate operating levels in order to preserve operational momentum. |
| Movement | MOV | The relocation of assets about the battlespace in order to support the mobility of the force. |
| Protection | PRO | The minimisation of risk in the battlespace in order to maintain force capability. |

It is possible to use these core skills to rate any force's effectiveness in each area. In general, various force structures have strengths and weaknesses in each area. For example, paratroops may have strengths in Information Collection and Movement but be weaker in other areas such as Engagement. On the other hand, an armoured formation may be stronger in Engagement but weak in Sustainment due to fuel needs. In addition, the relative strength of two competing forces can be easily analysed by comparing the capabilities in each core skill and identifying how that would impact on the other core skills. For instance, improving a force's protection capability would impact on the relative engagement capability of an enemy combatant.

## 2.2 MANA

### 2.2.1 Description

The exploratory nature of this study required a simulation tool that could easily create simple tactics and rules for units to follow. The tool had to be able to focus on the behavioural aspects of a force, abstracting technical details such as weapon characteristics. In addition, given that we have limited knowledge of specific technical information and the physical form of the systems, it is necessary to have a simulation tool that is non-prescriptive and allows broad insights and understanding as to the functioning of the systems given a particular environment. Finally, since this study uses largely unscripted scenarios the simulation tool must be flexible enough to allow unexpected events to happen. ABDs were chosen as they have this functionality [10]. ABDs give us a window for focusing subsequent analysis, thereby providing the opportunity to inform the development of less abstract models and simulations.

The simulation tool of choice for this study was MANA. MANA is one of the more popular ABDs in use within DSTO and New Zealand's Defence Technology Agency (DTA) [7, 11]. It provides the user with a closed set of triggers and related states that the agents within the simulation follow. These triggers allow varying levels of control of the agents, allowing the required unscripted nature of the scenarios to emerge. MANA allows for characteristics or meta-personalities to be built up from sets of simple rules, whose interaction is not necessarily linear or predictable. It also provides facilities to quickly create and replicate meaningful scenarios. Finally the ease-of-editing present in the scenario input files enables batch methods of scenario creation, which was particularly useful for this study. In fact, all of the playoff scenarios were generated by an automated program.

We note that MANA is still in development, with continual upgrading and improvement. As such, using MANA was not without its problems. For instance, a software bug was discovered in the movement algorithm during routine testing. As discussed in Appendix G, it caused a bias to occur in every scenario, dependent on the relative starting positions of the two combatants. An updated version of MANA fixed this problem. In all cases, particular care was taken to test the simulation and models to verify that the simulation software acted as it should, and that the models operated as would be expected.

### 2.2.2 Default MANA Configuration

Before any base tactics were placed in MANA, a default scenario was created. This scenario was created using the default scenario that MANA provides, with some changes. The default MANA scenario places a single red entity and a single blue entity at the centre top and centre bottom of a 200x200 terrain, respectively. Each entity has a waypoint leading towards its opponent's position, so that they will meet in the middle of the terrain.

From this, the following changes were made to create the default scenario for this study:

- The number of entities was increased to 50 for each side
- The probability for kill of all entities at all ranges was set to 0.1
- The firing range for all entities was set to 15
- The sensor range for all entities was set to 20

The first two changes are to ensure that the scenario lasts long enough for the effects of implemented tactics to take place. The second two changes ensure that agents will see each other before they are within firing range, giving tactics a small amount of time to take action before battle begins. All scenarios end when any entity reaches its waypoint. Figure 1 through to Figure 4 show snapshots of the default scenario in action, from starting positions until the scenario terminates.

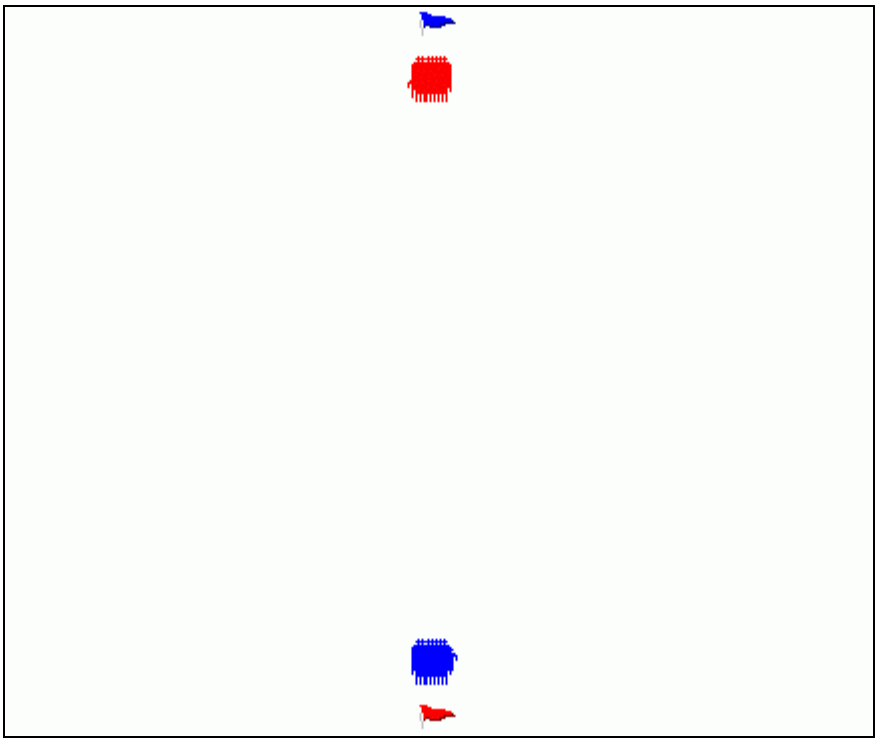

*Figure 1 - Default Scenario starting positions and waypoints*

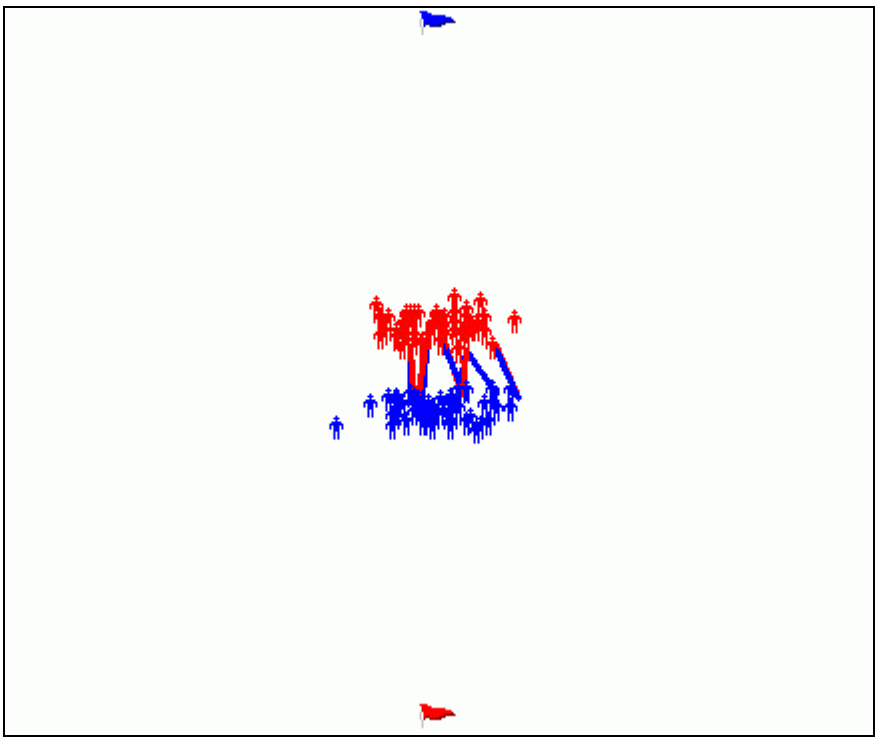

*Figure 2 - Default Scenario as the forces meet*

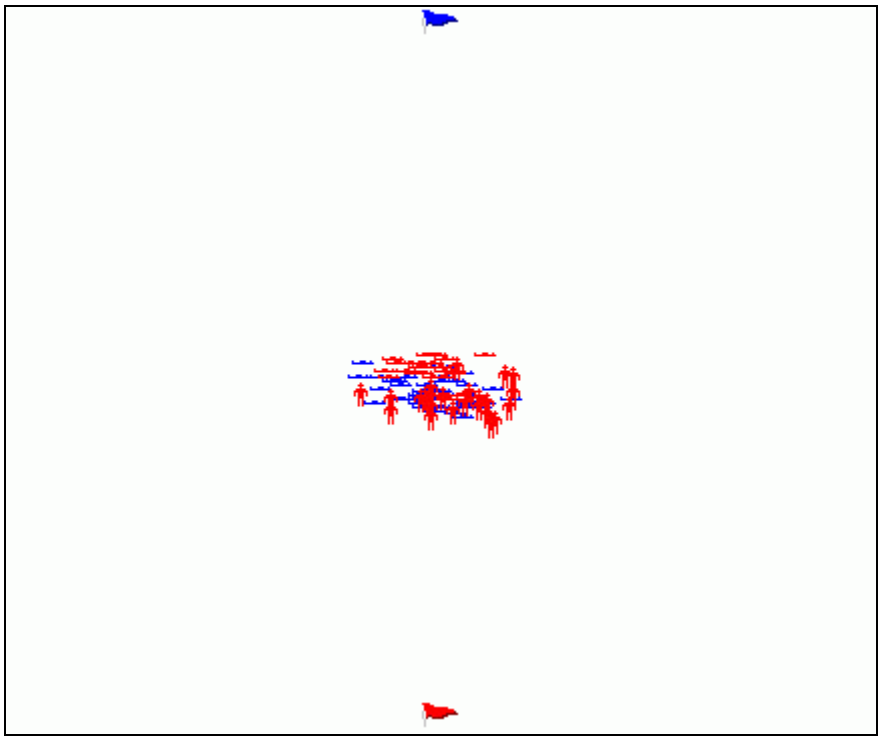

*Figure 3 - Default Scenario as the battle finishes*

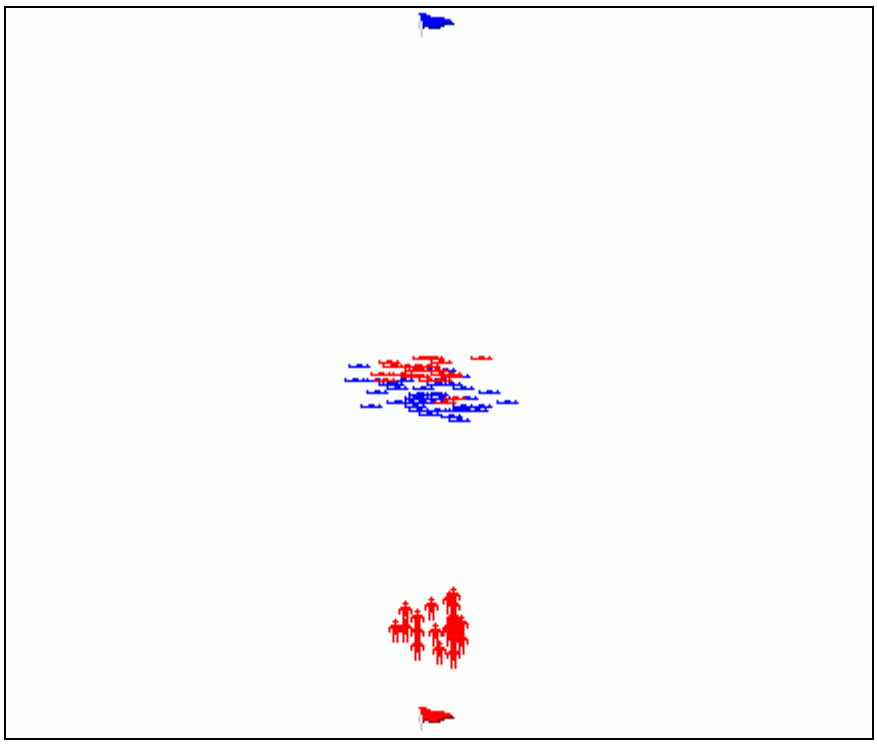

*Figure 4 - Default Scenario as the scenario terminates*

## 2.3 Development of Tactics

### 2.3.1 Base Tactics

The basis for this study was constructed using a set of 11 'base tactics'. For the most part, tactics that generally only provide linear improvements in force effectiveness were avoided. For example, improving a force by simply increasing the effectiveness of its body armour tends to have predictable effects consistent with the Lanchester equations. However, for completeness, one 'linear' tactic was included, that of increasing the firepower of the force. Table 2 shows the base tactics developed.

The choice and development of tactics focused on improving a force's conduct on the battlefield, rather than the salient features of the force. In creating the tactics, care was taken to keep them fairly simple. This formed a conflict with the other desire to avoid 'linear' tactics, as tactics that form potentially non-linear outcomes are inherently more complex. Therefore tactics had to be chosen from a fairly narrow band of possibilities. These restrictions made creating the base tactics the most challenging aspect of the study. Table 3 describes the base tactics in detail.

*Table 2 - Base Tactics and their weightings in each core skill area*

| BtID | Tactics | ENG | IC | COM | DM | SUS | MOV | PRO |
|---|---|---|---|---|---|---|---|---|
| | DEFAULT | | | | | | | |
| 1 | Back off then attack | | | | | | 1 | |
| 2 | Better Firepower (10%) | 1 | | | | | | |
| 3 | Combat Advantage | | | | 1 | | | |
| 4 | Re-org on Shot at - get Stealth | | | | | | | 1 |
| 5 | Retreat to friends when shot at | | | | 0.6 | | 0.4 | |
| 6 | Sight En - Chase | | 1 | | | | | |
| 7 | Sight En - Cluster - Attack | | 0.5 | | | | 0.5 | |
| 8 | Sight En - Envelopment | | 0.2 | | 0.5 | | 0.3 | |
| 9 | Sight En - Flanking | | 0.5 | | | | 0.5 | |
| 10 | Slow down on contact | | | | | | 1 | |
| 11 | Stealthier when shooting | 0.7 | | | | | | 0.3 |

*Table 3 - Base tactic descriptions*

| BtID | Tactic | Description |
|---|---|---|
| | DEFAULT | The force moves towards its only waypoint, situated at the starting location of its enemy. |
| 1 | Back off then attack | The force backs away from the enemy once sighting them, using a small clustering weight to ensure they do not fan out to the flanks. After 20 time steps of retreat, they attack. |
| 2 | Better Firepower (10%) | The force has a 10% better chance to hit when firing (0.11 instead of 0.1) |
| 3 | Combat Advantage | The force only advances when it thinks it has a numerical advantage, otherwise it will retreat. This tactic is triggered on sighting the enemy on a per-unit basis. |
| 4 | Re-org on Shot at - get Stealth | Once shot at, a member of the force goes into a cycle where, if they are not shot at again within 3 time steps, they are perceived to have found cover, and gain a stealth advantage for the next 10 time steps. |
| 5 | Retreat to friends when shot at | When shot at, a member of the force moves towards friends and away from enemies for 5 time steps. |
| 6 | Sight En - Chase | Once sighting the enemy, the force will chase enemies within sensor range. |
| 7 | Sight En - Cluster - Attack | Once sighting the enemy, the force will cluster very tightly, and attack slowly towards the enemy. |
| 8 | Sight En - Envelopment | Once sighting the enemy, the force will retreat and fan out towards the flanks, then attack as one, to attempt an envelopment manoeuvre. |
| 9 | Sight En - Flanking | Once sighting the enemy, the force will move as one towards the right flank, and attack the enemy in the side. |

| BtID | Tactic | Description |
|---|---|---|
| 10 | Slow down on contact | Once sighting the enemy, the force will slow to half its usual speed, to simulate a more controlled force that does not rush into battle. |
| 11 | Stealthier when shooting | When a member of the force takes a shot, it becomes stealthier for 5 time steps. |

Table 2 shows our interpretation of the weightings in each core skill area that the tactics received. Each of these tactics is referenced by a Base Tactic ID (BtID), from Bt1 to Bt11. These weightings represent the areas a force is deemed to be proficient in when using the particular tactic. For example a force using Bt2: Better Firepower is more proficient at Engagement, but has no specific proficiencies in any of the other categories. This is not to mean that a force using this tactic has no capability in these other areas, instead it means their proficiency in the other core skills is equivalent to a baseline force. This weighting system is how the tactics developed are mapped back to the AAAS core skills. While these basic tactics may not be a complete set, they are sufficiently comprehensive to provide insight into the majority of core skills. Finally, it is to be stressed that we are investigating tactics here and thus there mostly no change in the input parameters, except in Bt2, Bt4 and Bt11.

The obvious exceptions are Sustainment and Communications. Implementing Sustainment required more complex force structures than the ones to be used in this study. It would be possible to implement Communications into the structure used, but it would have required special attention to implement from a modelling point of view, which we were not prepared to provide. We note, however, that the tactics identified appear largely to be communications and sustainment neutral.

Note also that in modelling Decision Making we did not model the decision making process itself, but rather the effects of good decision making. Decision Making is definitely the hardest of all core skills to model, as it is the most intangible.

### 2.3.2 Combinations of Base Tactics

From the simple base tactics described earlier, more complex combined tactics were built up. This was achieved by combining various pairs of base tactics. Each of these combinations was tested against a default red force. The results are compared with base tactics results to determine the performance improvements gained by combining various tactics and hence, core skills.

It was not possible to combine all the base tactics into combinations. Various pairs of tactics were impossible to combine. An example of a combination that will not work is Bt8: Sight En – Envelopment and Bt9: Sight En – Flanking. In this case, the actions that each tactic specify to perform upon sighting an enemy are incompatible. Note that it may be possible to produce a tactic that employs both envelopment and flanking (such as flank the enemy then start the envelopment action), however the resulting tactic

would not be a 'pure' combination of the original two tactics, each of which specify that their action is to be performed on sight of the enemy.

We note that some further effort went into combining three base tactics to further explore the effectiveness of combinations of tactics. The method is essentially the same as combining two tactics, only there is an increased incidence of clashing triggers, reducing somewhat the possible sample space. This area was not explored extensively as the broad skill sets these tactics produced are not the main focus of the study.

### 2.3.3 Playing off Tactics

As noted in section 2.3.2, the various tactics that the blue force employed were played against a default red force. In this section, tactics or combinations of tactics are given to both sides and played against each other. Two types of playoffs were used, the case where the red force was given a single base tactic (2v1 playoffs), and the case where the red force was given a combined tactic (2v2 playoffs).

These types of scenarios add an extra dimension to the analysis being performed. Instead of being tested against default opponents, skill combinations can be weighed up against each other, potentially showing optimal skill sets to use against various opponents.

### 2.3.4 Use of Blockage

To add another dimension to the scenarios, the idea of blockage was introduced. Conceptually, 'blockage' may represent some sort of terrain feature, be it hills, buildings or vegetation. Several blocks of walls that block movement, line of sight and weapon fire were placed in the centre of the battlefield. The blocks were created so as to impede movement without having them completely shape the battle. For each scenario run, be it base tactics, combinations of tactics or playoffs, a sister scenario with blockage introduced was also run. Addition of blockage is an easy way to add complexity to the scenarios, allowing an increased possibility of emergent properties to arise. Figure 5 shows the default scenario in action, this time with blockage introduced.

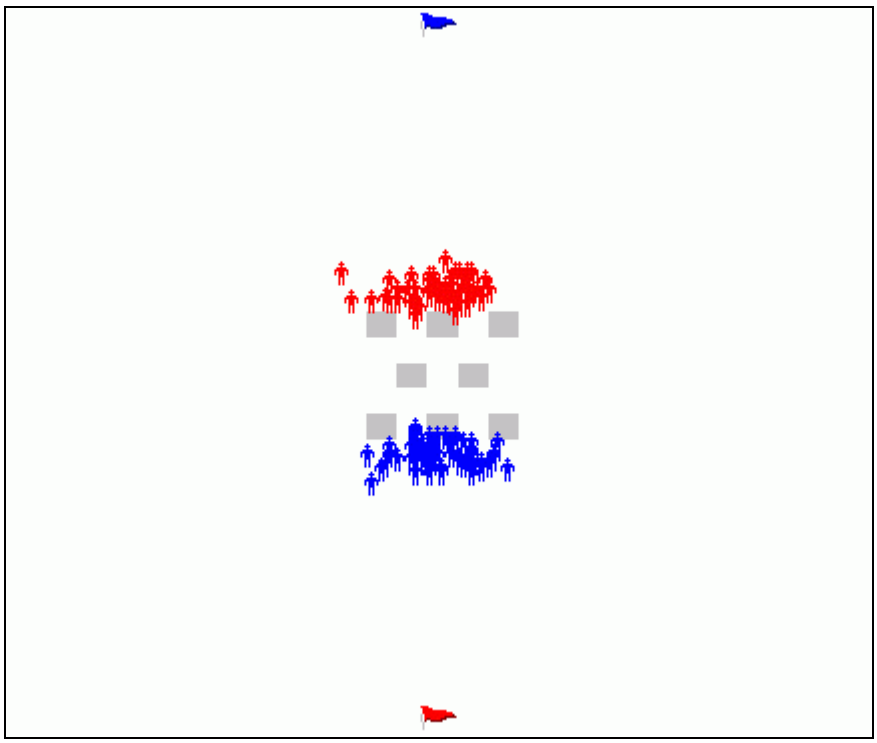

*Figure 5 - Default scenario with blockage introduced*

## 2.4 Performance Measurement Methods

The objective of this study was to identify synergy between core skills, instead of simple scenario performance. Therefore, traditional methods such as loss exchange ratio (LER) become inadequate, as they only analyse individual scenario performance and not relative performance against expectations, as is required here. Therefore an alternative measure was developed to meet this need.

The basis for performance measurement was decided to be casualty difference (red casualties – blue casualties), which is deliberately the simplest method available. We can then predict expected casualty difference of more complicated scenarios using the casualty difference of the component tactics that form the scenario. This expected casualty difference was deemed to be the addition of the casualty difference of the component tactics. An example is presented below, with two imaginary base tactics, called A and B.

*Table 4 - Example base tactics*

| Tactic | Blue Casualties | Red Casualties | Casualty Difference |
|---|---|---|---|
| A | 38 | 44 | 6 |
| B | 26 | 35 | 9 |

When played alone against a default red force, the tactics produce the results seen in the above table. Therefore, the expected casualty difference of a force which uses both A and B (call this combined tactic AB) would be (6 + 9 = 15). This combined tactic is then also played against a default red force. The casualty difference measured from that scenario has the expected casualty difference subtracted from it to form a measure of synergy of tactics A and B. Therefore, if this combined tactic produces a casualty difference of 17, then the performance of the combined tactic AB becomes (17 - 15 = 2). In this study, we use the word 'performance' as the descriptor for the level of synergy or antagonism certain combined tactics (and therefore core skills) have and appears all the results tables from Table 17 to Table 22.

If we then move into the realm of playing off tactics, the expectation system works similarly, except that tactics given to the red side have the opposite effect on the expected casualty difference of a scenario. Note that when using combined tactics in playoffs, we use the actual casualty difference of the combined tactic in the calculation, instead of the expected casualty difference. To provide an example, we will introduce a third base tactic, called C, whose casualty difference is 5. If we then create a scenario where tactic AB faces C, then expected casualty difference from this scenario becomes (17 – 5 = 12). If the actual casualty difference is 8, then we measure the performance of AB against C as (8 – 12 = -4), meaning that C is performing better than expected against AB. We see that in this example, AB still won the battle. The system however rates it badly on the basis that AB was expected to perform better than it did.

These linear methods provided a useable scale for measuring synergies between core skills. However, in some instances they proved to be problematic, particularly when results tended toward the extreme ends of the measurement scale, where forces become so effective that further improvement produced lower payoff results. Also, it is important to note that this method is a measure of synergy, not of particular tactic effectiveness.

# 3. Results

## 3.1 Base Tactics Results

Having identified tactics and modelled them in MANA, we were able to commence our analysis of the relative effectiveness of the tactics. The first element of this considered the absolute effectiveness of single tactics against a default enemy force. This provided a sense of the relative strength of each tactic against a default opponent. Table 5 shows the results for 1000 replications in MANA of each base tactic. The results indicate that in most instances, the introduction of a tactic enhanced the force capability. In three instances, Bt1 (Back off then attack), Bt5 (Retreat to friends when shot at) and Bt7 (Sight En – Cluster – Attack), blue capability improved markedly, both

in terms of fewer blue casualties and greater red losses. However, as these tactics are relatively simple and against a deliberately simple threat, little in the way of direct observations can be made. We note, though, that they provide the basis for capturing the relative merit of all future combinations of tactics.

*Table 5 - Base Tactics Results*

| BtID | Tactics | Avg Blue Casualties | Avg Red Casualties | Casualty Difference |
|---|---|---|---|---|
| | DEFAULT | 39.36 | 39.45 | 0.10 |
| 1 | Back off then attack | 31.04 | 48.53 | 17.50 |
| 2 | Better Firepower (10%) | 35.78 | 43.42 | 7.64 |
| 3 | Combat Advantage (Take 2) | 39.09 | 44.78 | 5.70 |
| 4 | Re-org on Shot at - get Stealth | 39.56 | 39.36 | -0.20 |
| 5 | Retreat to friends when shot at | 23.23 | 48.64 | 25.41 |
| 6 | Sight En – Chase | 40.04 | 41.54 | 1.50 |
| 7 | Sight En - Cluster – Attack | 18.52 | 49.30 | 30.79 |
| 8 | Sight En – Envelopment | 42.64 | 39.20 | -3.44 |
| 9 | Sight En – Flanking | 36.63 | 44.17 | 7.53 |
| 10 | Slow down on contact | 34.82 | 44.81 | 9.99 |
| 11 | Stealthier when shooting | 38.56 | 40.43 | 1.87 |

## 3.2 Combined Tactics Results and Analysis

### 3.2.1 Developing tactical pairs

Mentioned above are three base tactics (Bt1, Bt5 and Bt7) that performed very well in the initial runs, destroying the red force and suffering few casualties themselves. As these tactics perform so well on their own, impacts of combining tactics would be very difficult to see and tend to skew the results. Therefore, only two representative combinations were developed using these three base tactics, though some were used when playing off tactics.

Each combined scenario carries with it a weight in each core skill, based on the base tactics that create it. To determine the weight for a particular core skill in a combined tactic, the weights for this core skill in the base tactic are averaged. Therefore, if Sight En – Flanking (IC 0.5, MOV 0.5) is combined with Slow Down on Contact (MOV 1.0), then the resulting combined tactic will be rated (IC 0.25, MOV 0.75). These weightings are displayed in Appendix A.

An indication of which scenarios were combined is presented in Table 6.

*Table 6 - Combinations of Base Tactics Developed*

| Base Tactic ID (BtID) | Base Tactic ID (BtID) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 1 | X | Ct2 | Ct3 | N | N | N | N | I | N | N | N |
| 2 | X | X | Ct4 | Ct12 | N | Ct16 | N | Ct8 | Ct17 | Ct18 | Ct1 |
| 3 | X | X | X | Ct15 | N | I | N | Ct14 | Ct11 | Ct13 | Ct10 |
| 4 | X | X | X | X | N | Ct19 | N | I | Ct5 | Ct6 | I |
| 5 | X | X | X | X | X | N | N | N | N | N | N |
| 6 | X | X | X | X | X | X | N | I | I | Ct20 | Ct21 |
| 7 | X | X | X | X | X | X | X | N | N | N | N |
| 8 | X | X | X | X | X | X | X | X | I | Ct22 | Ct9 |
| 9 | X | X | X | X | X | X | X | X | X | Ct23 | Ct7 |
| 10 | X | X | X | X | X | X | X | X | X | X | Ct24 |
| 11 | X | X | X | X | X | X | X | X | X | X | X |

Key:

| | |
|---|---|
| X: | Redundant |
| Ct1-24: | CtID of completed combined scenario |
| N: | Not completed due to over-performance of base scenario |
| I: | Base tactics are mutually exclusive |

Appendix A shows the results of replicating each of these combined tactics 1000 times. against a default opponent. Each combined tactic is referenced by a Combined Tactic ID, or CtID, from Ct1 to Ct24. For each scenario the method described in section 2.4 was used to measure the performance of the combined tactic.

### 3.2.2 Scenario Performance – Best and Worst

Figure 6 shows that three combined tactics (Ct10, Ct14, and Ct22) outperform every other tactic by close to an order of magnitude. The remaining results were centred on the origin. These three scenarios, along with the next best performing tactic (Ct23) are shown in Table 7.

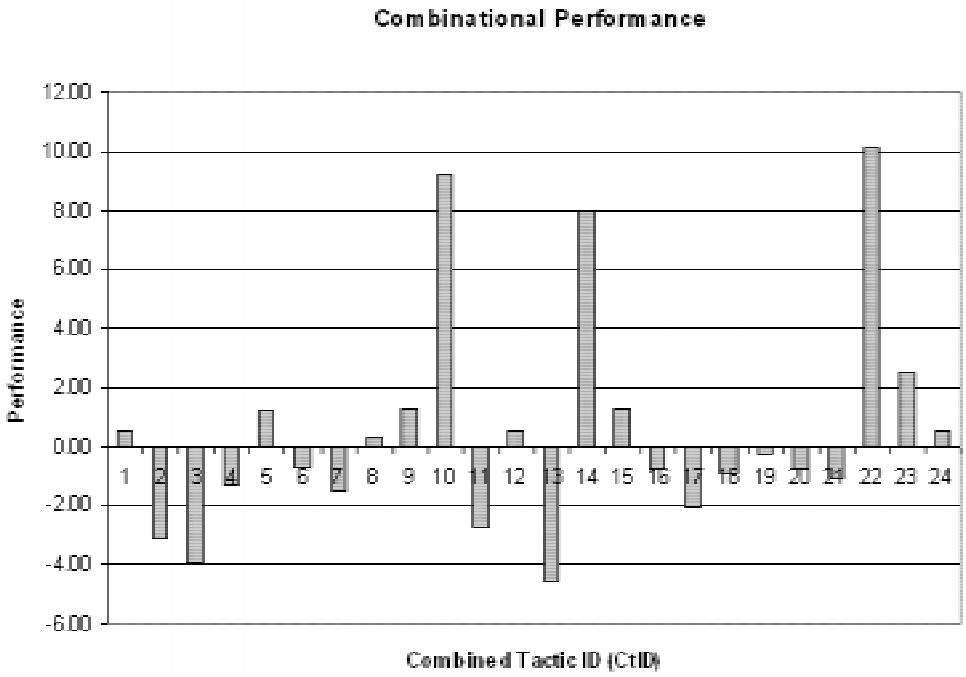


*Figure 6 - Combined tactics performance*

As Table 7 shows, these four scenarios tend to imply that combining Movement with Decision Making has a high-payoff effect on force effectiveness. Against the onrushing opposing force, tactics strong in these skills seem to intelligently position themselves to inflict a large amount of casualties. Adding Information Collection to this mix (Ct14 and Ct22) also had a positive effect.

Table 8 describes four of the worst performing scenarios (although two of these are concatenated into a single row of Table 8). These scenarios did not under-perform as markedly as the top four scenarios over-performed. Given that combat advantage was part of all three, it might indicate that it did not combine well with certain other tactics. Interestingly, Combat Advantage did figure in two of the best performing combinations. Hence there is a degree of sensitivity to the way in which this tactic integrated with other tactics. Any advantage appears to be lost if the blue force were not aggressive in their use of combat advantage. Certainly in the best performing scenarios where Combat Advantage was employed, the blue force used movement in a tactically offensive manner.

Another insight was that Decision Making and Movement are involved in all three of these under-performing scenarios. This is, in part, a function of the impact of combat advantage. However, the high prevalence of Movement and Decision Making in both the best and worst performing tactics suggests that the outcomes and effectiveness of employing these skills are very prone to the form which these skills took, how they were employed and the ways in which they were combined.

*Table 7 - Best Performing Combined Tactics*

| CtID | Scenario Name | Weightings | Comments |
|---|---|---|---|
| 22 | Sight En – Envelopment + Slow down on contact | MOV 0.65, DM 0.25, IC 0.1 | Slowing down the envelopment had a large positive effect, as the blue forces were able to fan out along a line and bring to bear more of their firepower in comparison to red. So effective was this, that blue did not even begin the second phase of its envelopment (the attack) before the red force was eliminated. |
| 14 | Combat Advantage + Sight En – Envelopment | DM 0.75, MOV 0.15, IC 0.1 | The base envelopment scenario often failed because one flank tended to be weakened and destroyed rather easily when blue thinned out their numbers attempting to achieve the envelopment. Adding combat advantage helped lessen the localised weakness caused by collapsing flanks. In this case, as a flanking unit was being depleted, it tended away from the enemy, either inward and closer to friends, or outward away from the battle. |
| 10 | Combat Advantage + Stealthier when shooting | ENG 0.35, DM 0.5, PRO 0.15 | It was unclear why this particular combination performed so effectively. |
| 23 | Sight En – Flanking + Slow down on contact | MOV 0.75, DM 0.25 | Slowing down during the flanking manoeuvre had the effect of the blue force working on a small piece of the red force at a time, as it pushed through the flank and towards the centre of the red force. This caused a localised numerical advantage. Slowing down the force is representative of a more controlled attack. |

*Table 8 - Worst Performing Combined Tactics*

| CtID | Scenario Name | Weightings | Comments |
|---|---|---|---|
| 3 | Back off then attack + Combat Advantage | DM 0.5, MOV 0.5 | Back off then attack was one of the base scenarios marked in Section 2.3 as over-performing. This scenario appears to perform badly but the reason behind this is that it is difficult to improve such a well performing base scenario. ID 2: Back off then attack + Better Firepower (10%) under-performs to a similar level for the same reasons. Therefore it was omitted from this table. |
| 13 | Combat Advantage + Slow down on contact | DM 0.5, MOV 0.5 | It was unclear why this combination under-performed. Possibly the relative improvement due to combat advantage movement was decreased by the slow down tactic, so the blue units exploited weaknesses more slowly. |
| 11 | Combat Advantage + Sight En – Flanking | IC 0.25, DM 0.5, MOV 0.25 | It was unclear why this scenario under-performed. |

### 3.2.3 Combinational Strengths

Using these results it is possible to measure the combinational strengths of pairs of core skills. For each combined tactic, pairs of core skills were extracted and rated according to how the tactic performed. The formula used is again simplistic. The combinational strength of a particular pair of core skills is expressed as:

$$\frac{(W_{s1}+W_{s2})}{(n-1)} * R \qquad \text{Equation (1)}$$

where $W_{s1}$ and $W_{s2}$ are the weights of a particular skill in the tactic (noting that skills have a weight between 0 and 1 for their presence in a particular tactic), $R$ is the performance of the tactic as measured by the ratings system and $n$ is the number of skills that are more proficient than normal in the tactic. This formula represents how well a core skill combination has performed (the higher the better).

For example, if a tactic comprised three core skills, (eg MOV 0.5, ENG 0.3, PRO 0.2) and its performance was measured at +5.0, the combinational strength of Movement and Engagement is then:

$$\frac{0.5+0.3}{3-1} * 5.0 = 2.0 \qquad \text{Equation (2)}$$

For Movement and Protection:

$$\frac{0.5+0.2}{3-1} * 5.0 = 1.75 \qquad \text{Equation (3)}$$

And finally for Engagement and Protection:

$$\frac{0.3+0.2}{3-1} * 5.0 = 1.25 \qquad \text{Equation (4)}$$

Note the sum of the values in Equations (2), (3) and (4) add up to the rating provided as input. This is the effect of the ($n$-1) value, since each skill weight appears ($n$-1) times.

This breakdown is performed for each scenario in a set of runs, and the results are placed into the appropriate cell of a matrix, whose rows and columns represent the core skills. Each new value is added onto the total previously present in the cell. The values in Table 9 and Table 16 are the aggregation of 24 scenarios, whose raw data can be found in Table 17 and Table 20 respectively.

*Table 9 - Combinational strengths for pairs of skills (un-calibrated)*

| | ENG | IC | DM | MOV |
|---|---|---|---|---|
| PRO | 3.152 | -0.287 | 4.395 | -0.156 |
| MOV | -4.621 | 5.480 | -1.175 | |
| DM | 2.886 | 4.287 | | |
| IC | -2.098 | | | |

From Table 9 we see that Decision Making tends to combine rather well with the other core skills, with Movement as the exception. We can also see that Engagement and Movement do not combine well together, but Information Collection and Movement do.

Results from this table must be taken with a certain grain of salt. The process is highly susceptible to contamination from outliers. Despite this, insights such as the ones above may be useful in corroborating other evidence found later on.

## 3.3 Playing off tactics against one another

### 3.3.1 Combined Blue Tactics versus Single Red Tactic

Of course, both sides of any conflict can and will employ tactics to help in achieving their aim. Therefore, further insights can be gained by seeing how well each side can use tactics. The first round of such playoffs involved playing a blue force using a combined tactic against a red force using a single base tactic (2v1 playoffs). Given the number of base and combined tactics, there were 264 possible scenarios in this section. In order to keep the study manageable, only a selected subset of these were chosen. For the most part, four selected base tactics were used. These were Better Firepower, Re-org on shot at – Stealth, Retreat to friends when shot at, and Sight En – Flanking. These are Bt2, Bt4, Bt5 and Bt9 respectively. They were selected because they represent a broad range of tactics, from the largely linear and predictable Better Firepower, to the unpredictable Sight En - Flanking. Combined tactics were for the most part limited to the best and worst performing tactics. The combined tactics were selected in this manner on the assumption that tactics that showed unusual behaviour to begin with are more likely to show more unusual behaviour when used in subsequent trials. The detailed results of these playoffs are presented in Appendix B, with the performance column of Table 18 calculated in accordance with section 2.4. Further work will integrate 1v1 tactics (single base tactics against each other), which was not explored in this study.

Table 10 presents a frequency distribution summary of the results of these 2v1 playoffs. Once again, each scenario is referenced by an ID number, this time designated a PsID, from Ps1 to Ps33. For the most part, scenarios perform as expected but there also appear to be a few scenarios where results significantly diverged from predictions. Also it is worth noting that there is an apparent gap in the 5-10 range. However the dataset is too small to draw any conclusions.

*Table 10 - Distribution of results in single red tactic playoffs*

| Performance | Frequency |
|---|---|
| 0-5 | 24 |
| 5-10 | 1 |
| 10-15 | 3 |
| 15-20 | 3 |
| 20-25 | 2 |

The scenarios where the difference was between 10 and 25 were investigated more closely. These scenarios are of the most interest to this study as they represent occurrences of non-linear relationships between tactics. Analysis of these scenarios is provided in Table 11. Here the shaded tactics indicate the tactic performing better than expected. The most important insight gained from Table 11 was that positioning of forces was the major factor in the unexpected performance of a scenario. Therefore, effective integration of movement appears to be a major contributing factor to the success (or otherwise) of a force.

*Table 11 - Extreme scenarios for 2v1 playoffs*

| PsID | Blue Tactic | Red Tactic | Difference from expected result | Comment |
|---|---|---|---|---|
| 1 | Sight En – Envelopment + Slow down on contact (IC 0.1, DM 0.25, MOV 0.65) | Sight En – Flanking (IC 0.5, MOV 0.5) | -24.14 | Both blue and red tactics triggered at the same time, but when the enveloping tactic attempts to close in the red force was already on its flank. The thinly spread blue force was attrited as the red force worked through its flank. |
| 4 | Sight En – Envelopment + Slow down on contact (IC 0.1, DM 0.25, MOV 0.65) | Retreat to friends when shot at (DM 0.6, MOV 0.4) | -13.75 | The red tactic had a clustering effect on the force, heavily concentrating the centre of gravity at the centre of the blue envelopment. The subsequent blue force attack had little effect. |
| 8 | Combat Advantage + Sight En – Envelopment (IC 0.1, DM 0.75, MOV 0.15) | Retreat to friends when shot at (DM 0.6, MOV 0.4) | 17.80 | The addition of Combat Advantage to Envelopment does not particularly counter Retreat to friends when shot at, but it mitigates the damage caused by the tactic. The blue force does not over-commit to battle, skirting the edges of the red force. Subsequently the blue tactic performs well here not by winning the battle but by stalemating it. |
| 12 | Sight En – Flanking + Slow down on contact (IC 0.25, MOV 0.75) | Retreat to friends when shot at (DM 0.6, MOV 0.4) | -16.10 | The red tactic seemed to have the effect of adapting to the direction of the flank and arranging the red force in a way suited to meet the flank. |
| 13 | Better Firepower + Sight En – Chase (ENG 0.5, IC 0.5) | Sight En – Flanking (IC 0.5, MOV 0.5) | -10.90 | The blue units tended to chase the trailing end of the red force. In doing so, they increased their exposure to the flanking tactic. |
| 17 | Better Firepower + Sight En – Chase (ENG 0.5, IC 0.5) | Sight En – Envelopment (IC 0.2, DM 0.5, MOV 0.3) | -10.07 | This scenario comes out fairly evenly when in fact the blue tactic is expected to win. This was because, with the chase tactic, the blue units fall further into the envelopment trap. |
| 22 | Sight En – Envelopment + Stealthier When Shooting (ENG 0.35, IC 0.1, DM 0.25, MOV 0.15, PRO 0.15) | Sight En – Flanking (IC 0.5, MOV 0.5) | -21.52 | As with Ps1, the flanking tactic was able to move easily through the thinly spread blue force. |
| 29 | Combat Advantage + Better Firepower (ENG 0.5, DM 0.5) | Retreat to friends when shot at (DM 0.6, MOV 0.4) | 17.29 | As with Ps8, Combat Advantage made the blue force move out of the way of the clustered red force. However, unlike Ps8, the lack of envelopment caused Blue and Red to make direct contact, inflicting more casualties, spread evenly between both sides. |

Another observation was the stabilising effect Combat Advantage has on a force. In both scenarios where Combat Advantage was used, the tactic mitigated losses. As a result, a further 8 scenarios were developed, playing all the combined tactics used in the playoff runs against a red force using the Combat Advantage tactic (Bt3). These results are presented in Table 12.

*Table 12 - Further testing of the Combat Advantage tactic*

| Blue CtID | Red BtID | Blue Casualties | Red Casualties | Casualty Difference | Expected Difference | Performance |
|---|---|---|---|---|---|---|
| 22 | 3 | 42.57 | 45.62 | 3.05 | 10.96 | -7.91 |
| 14 | 3 | 39.08 | 45.59 | 6.50 | 4.53 | 1.98 |
| 23 | 3 | 44.55 | 43.03 | -1.52 | 14.30 | -15.82 |
| 16 | 3 | 43.66 | 42.31 | -1.35 | 2.69 | -4.04 |
| 20 | 3 | 47.01 | 40.92 | -6.10 | 5.05 | -11.15 |
| 9 | 3 | 36.63 | 44.84 | 8.21 | -5.97 | 14.19 |
| 4 | 3 | 41.89 | 45.61 | 3.71 | 6.35 | -2.63 |
| 12 | 3 | 41.07 | 43.14 | 2.07 | 2.28 | -0.21 |

In only two cases did Combat Advantage perform worse than expected. However, it is worth noting that in all scenarios the red force never achieves any major victories. Therefore it can be hypothesised that Combat Advantage, and its inherent core skill of Decision Making, are important in helping a side not lose a battle, though they do not necessarily lead to winning one.

In only one scenario (of the 8 displayed in Table 12) did blue perform better than expected, namely when the blue force uses the combined tactic of Envelopment + Stealthier when shooting. The key to this combination working effectively was the Envelopment tactic, which deceived red into advancing against an apparently dispersing blue force. The red force, heavy in Decision Making, seems to lack flexibility in other areas needed to counter the surprise of the Envelopment.

To better understand the nature of the countering within the scenarios, a visualisation tool called a Countering Graph was developed. This graph displays the performance of various skill combinations against each other, based on scenario results. This representation of the results from the playoffs is displayed in Figure 8. The thickness of each arrow represents the performance of the skill set at the start of the arrow compared with the performance of the skill set at the end of the arrow, with regard to the expected results. These levels are detailed in the Performance column in Table 18. The better performing skill set points to its lesser companion. The colours of the lines also represent the level of performance, as shown in the key provided. Finally, in order to make the graph cleaner, scenarios with performance below 3 were omitted, though a note is made for each skill set of how many omitted lines there are for that set.

Figure 7 explains the Countering Graph in detail.

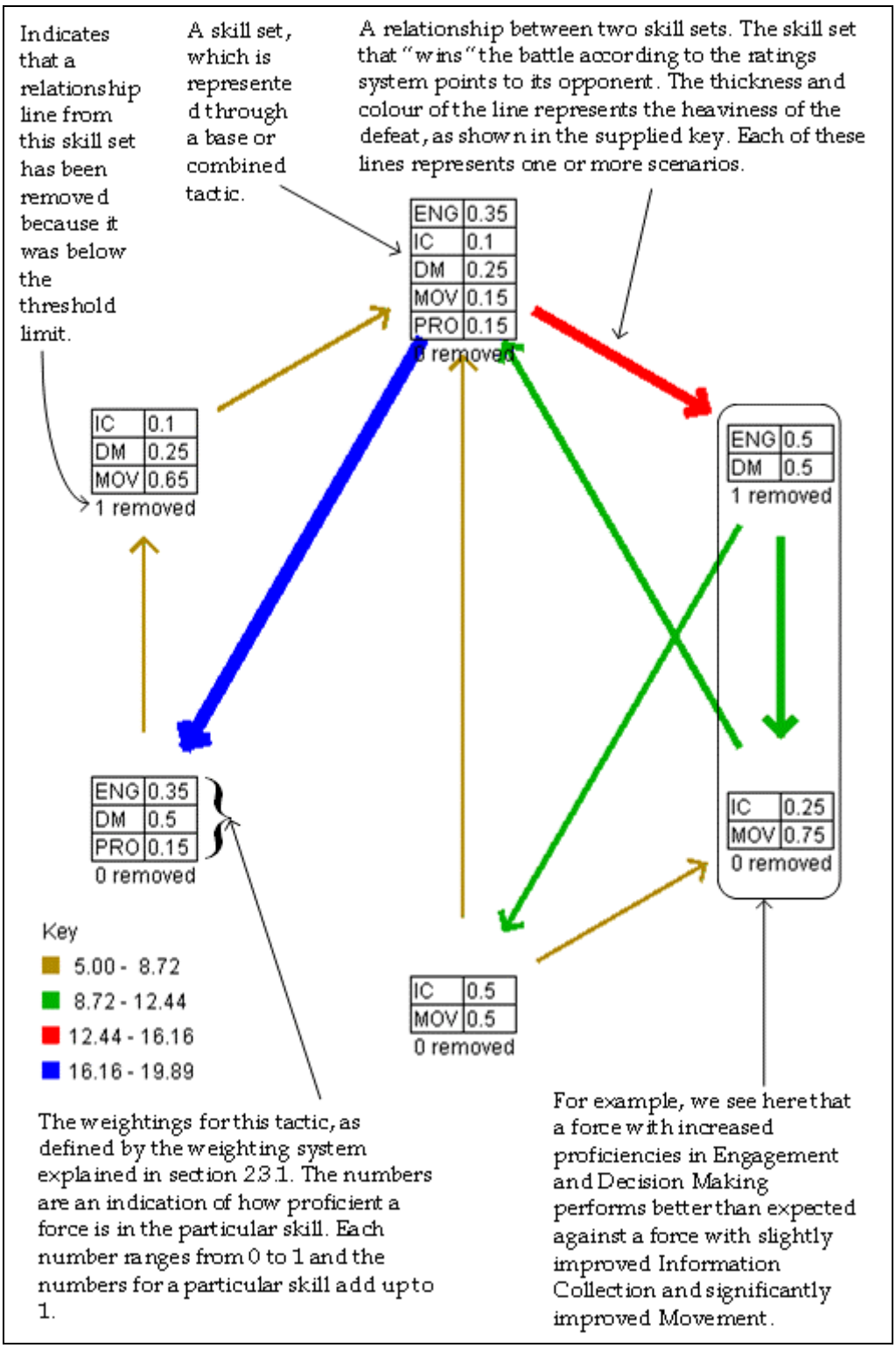


*Figure 7 - Illustrated Example of a Countering Graph*

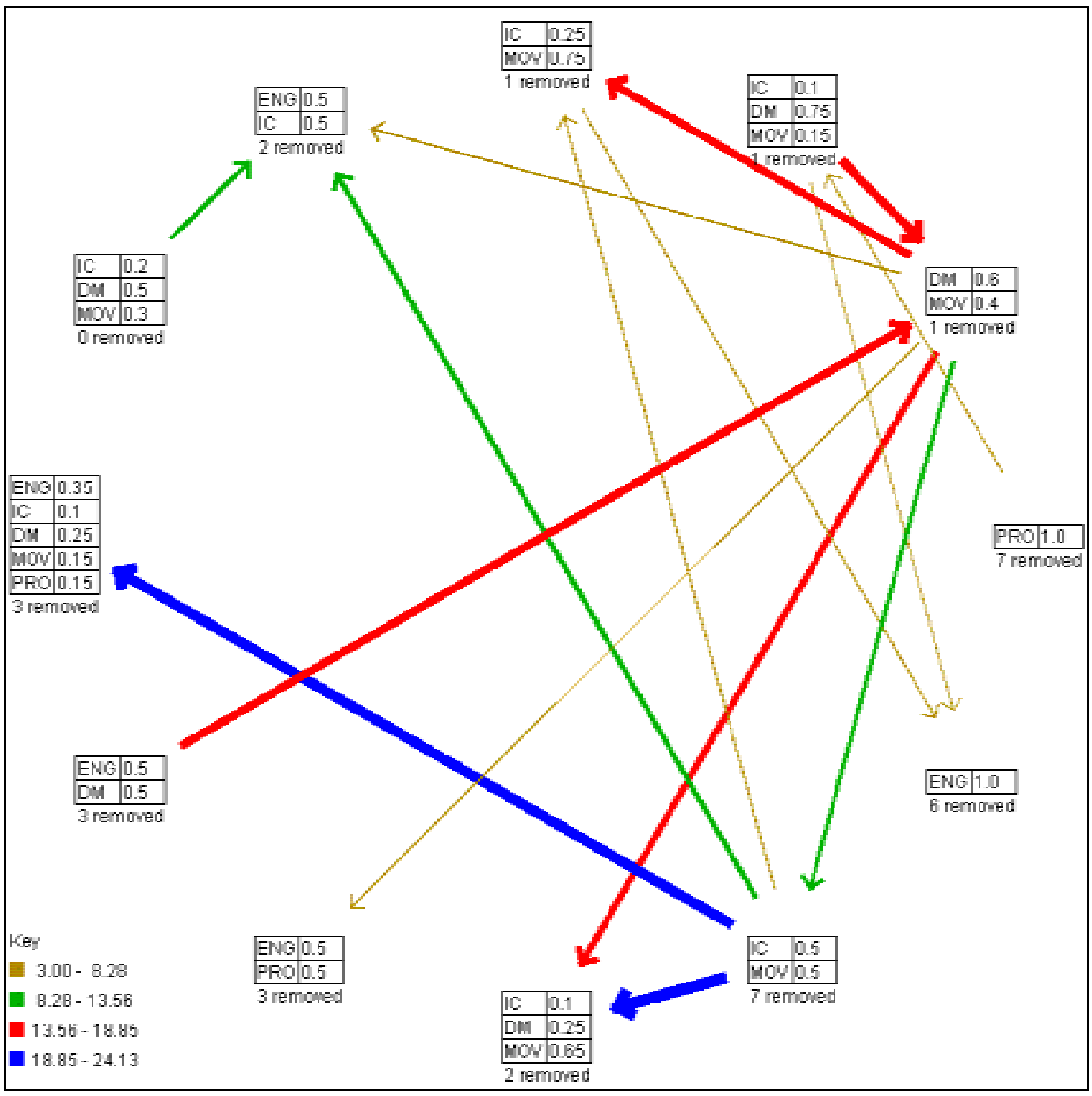


*Figure 8 - Countering Graph for 2v1 Playoffs*

A number of insights were gained from Figure 8, including:

- The lack of performance either positive or negative from the skill sets heavily involving Engagement and Protection. This suggests that the effect of these skills is largely linear.
- The lack of performance of Engagement and Information Collection together. This skill combination performs especially badly against tactics involving Decision Making, Information Collection and Movement.
- Forces strong in Decision Making tend to perform relatively well. All of these skill sets have one or more large positive performances in their favour. However, when these skill sets are played against each other, there are some

very significant reverses, notably (ENG 0.5/DM 0.5) versus (DM 0.6/MOV 0.4) and (IC 0.1/DM 0.75/MOV 0.15) versus (DM 0.6/MOV 0.4).

- The thinly spread skill set of (ENG 0.35/IC 0.1/DM 0.25/MOV 0.15/PRO 0.15) does not perform very well in any cases and indeed suffers a massive reverse at the hands of (IC 0.5/MOV 0.5).
- Many of the thickest lines appear in relation to skill sets involving Decision Making and Movement. We note that this trend was also present in the Combined Tactics (section 3.2.2).

### 3.3.2 Combined Red Tactic

The next run of scenarios involved playing combined tactics off against one another. The number of possible scenarios in this section was 276 so once again a subset of these was selected to make the study manageable. Blue and red force tactics were for the most part selected from the best and worst performing combined tactics, however some scenarios were constructed specifically to test certain core skill combinations against each other. The results from the 48 scenarios that were tested are displayed in full in Appendix C. Like the previous scenarios, each of these 48 scenarios is referenced by a unique identifier, called a PcID, ranging from Pc1 to Pc48.

A frequency distribution of the results is shown in Table 13. Note that unlike Table 10, the distribution of results in this case follows a normal distribution more closely.

*Table 13 - Distribution of results for combined red tactic playoffs*

| Difference from expected result | Frequency |
|---|---|
| 0-5 | 24 |
| 5-10 | 15 |
| 10-15 | 5 |
| 15-20 | 3 |
| 20-25 | 1 |

Once again our main interest is in scenarios that perform in the 10-25 range, since these scenarios have not performed as expected and are therefore showing some signs of synergy or antagonism. These 9 scenarios are presented in detail in Table 14. As can be seen, many of those results that performed outside of expectations can be explained in some way as the advantageous (or disadvantageous) combination of tactics. Hence, we have some ability to appreciate the emerging synergies or antagonisms of some combinations. For instance, when envelopment was played against flanking, one wing of the attempted envelopment loses contact with the opposition force and reverts back to its default tactic of moving towards the final waypoint. However, in some cases the reasons why certain scenarios performed as they did remain unclear.

*Table 14 - Notable scenarios in combined red tactic playoffs*

| PcID | Blue Tactic | Red Tactic | Performance | Comment |
|---|---|---|---|---|
| 4 | Better Firepower + Combat Advantage (ENG 0.5, DM 0.5) | Sight En – Envelopment + Stealthier When Shooting (ENG 0.35, IC 0.1, DM 0.25, MOV 0.15, PRO 0.15) | -15.59 | The Combat Advantage tactic, shown earlier to be robust against most tactics, is countered here by Envelopment. The blue force, sensing an advantage against the retreating red force, walks into the envelopment trap. |
| 11 | Back off then attack + Better Firepower (ENG 0.5, MOV 0.5) | Sight En – Flanking + Stealthier When Shooting (ENG 0.35, IC 0.25, MOV 0.25, PRO 0.15) | -13.99 | The blue force attempts to back off against a force that is already retreating. This causes some of the blue force to lose contact with the enemy and then as the flanking tactic changes direction, the blue force commits itself piecemeal and is destroyed. |
| 17 | Sight En – Envelopment + Stealthier When Shooting (ENG 0.35, IC 0.1, DM 0.25, MOV 0.15, PRO 0.15) | Sight En – Flanking + Slow down on contact (IC 0.25, MOV 0.75) | -10.07 | This scenario is another example of the flanking tactic defeating the envelopment tactic. |
| 20 | Combat Advantage + Stealthier when shooting (ENG 0.35, DM 0.5, PRO 0.15) | Sight En – Envelopment + Stealthier When Shooting (ENG 0.35, IC 0.1, DM 0.25, MOV 0.15, PRO 0.15) | -19.89 | As with Pc4, Envelopment defeats Combat Advantage. |
| 30 | Better Firepower + Combat Advantage (ENG 0.5, DM 0.5) | Sight En – Flanking + Slow down on contact (IC 0.25, MOV 0.75) | 12.34 | This scenario is another example of Combat Advantage mitigating the effect of other tactics. |
| 31 | Back off then attack + Better Firepower (ENG 0.5, MOV 0.5) | Sight En – Flanking + Slow down on contact (IC 0.25, MOV 0.75) | -20.51 | The result of this combination is similar to Pc11. The red force performs even better here because slowing down has a clustering effect. |
| 43 | Sight En – Envelopment + Slow down on contact (IC 0.1, DM 0.25, MOV 0.65) | Slow down on contact + Stealthier when shooting (ENG 0.35, MOV 0.5, PRO 0.15) | -15.48 | These three scenarios are grouped because of their similarity. In all cases, the red tactic performs better than expectations, although it is unclear why. Note also that in the raw results shown in Appendix C this force combination never performs below expectations. |
| 45 | Sight En – Flanking + Slow down on contact (IC 0.25, MOV 0.75) | Slow down on contact + Stealthier when shooting (ENG 0.35, MOV 0.5, PRO 0.15) | -12.61 | |
| 48 | Sight En – Envelopment + Stealthier When Shooting (ENG 0.35, IC 0.1, DM 0.25, MOV 0.15, PRO 0.15) | Slow down on contact + Stealthier when shooting (ENG 0.35, MOV 0.5, PRO 0.15) | -11.75 | |

### 3.3.2.1 *Countering Graph*

As for the single red tactic playoffs, a Countering Graph was established for this set of runs. This graph is shown in Figure 9.

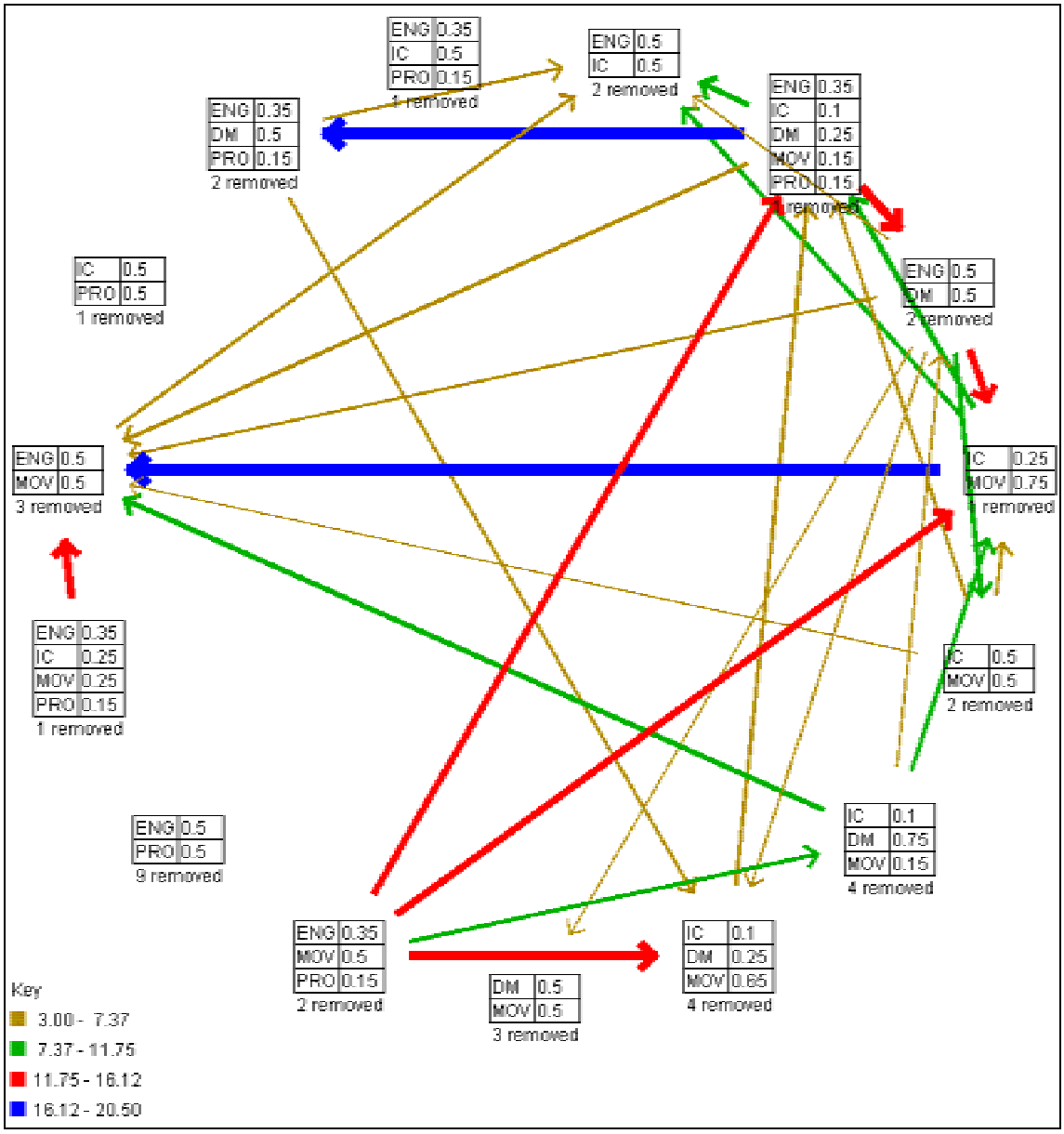


*Figure 9 – Countering Graph for 2v2 Playoffs*

Once again, there are many points that can be extracted from this graph:

- The skill sets of (ENG 0.5/MOV 0.5) and (ENG 0.5/IC 0.5) under-perform against nearly every tactic they face. This is not surprising as (ENG 0.5/IC 0.5) performed badly in the single red tactic playoffs as well. Indeed, in Table 9 these two skill combinations are the worst performing against a default red force.
- As previously mentioned, Engagement and Protection have a largely linear effect on force strength and this is confirmed here as the (ENG 0.5/PRO 0.5) skill set showed no deviating results.
- The skill set (ENG 0.35/MOV 0.5/PRO 0.15) defeated every tactic it faced, despite the fairly linear elements that compose half of it (Engagement and Protection). The addition of movement to this set garners a large positive effect.
- The skill set (ENG 0.35/DM 0.5/PRO 0.15) produces several occurrences of non-linearity in results. Once again, a force strong in Engagement and Protection produces results contrary to the expected linearity of these skills. This and the above point seem to suggest that including a third skill with Engagement and Protection starts to produce non-linear results.

One other interesting observation from Figure 9 is the appearance of a 'Rock-Paper-Scissors' effect. That is where there is a cyclical performance structure. As Figure 10 indicates, the central tactic (ENG 0.35, IC 0.1, DM 0.25, MOV 0.15, PRO 0.15) with its broad skill set is involved in all the observed cycles. In addition, the numerous cycles present in this graph can be compressed into a single cycle. This requires two sets of tactics to be grouped:

- (ENG 0.5/DM 0.5) and (ENG 0.35/DM 0.5/PRO 0.15) are compressed into a single category of 'Engagement/Decision Making heavy tactics'
- (IC 0.1/DM 0.25/MOV 0.65), (IC 0.5/MOV 0.5) and (IC 0.25/MOV 0.75) are compressed into a single category of 'Information Collection/Movement heavy tactics'

As Figure 11 shows, this then condenses down to a simple loop with combinations heavy in Engagement/Decision Making being superior to those heavy in Information Collection/Movement that in turn, are superior to a Broad Skill Set, which appears superior to the first combination.

There is room here for further investigation into this phenomenon, to determine whether or not it is merely an aberration. This could be in the form of more simulation-based analysis, either through an abstract simulation or a higher resolution wargame, or a parallel historical study.

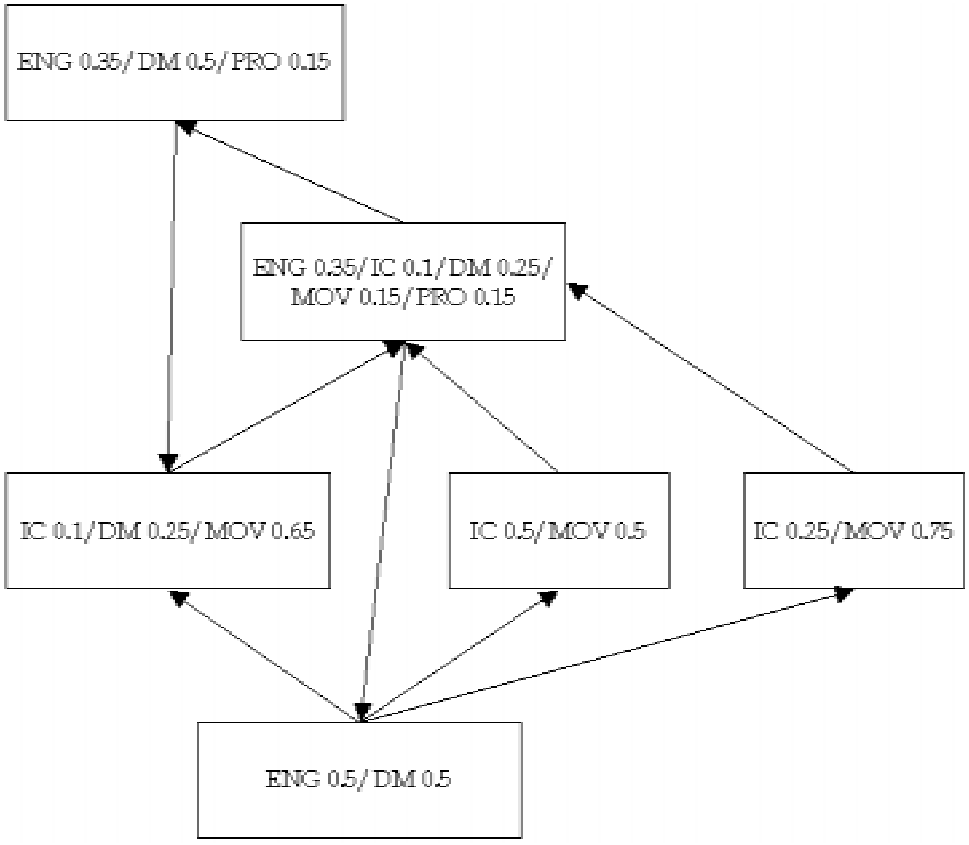


*Figure 10 – Instances of the 'Rock-Paper-Scissors' effect in playoffs*

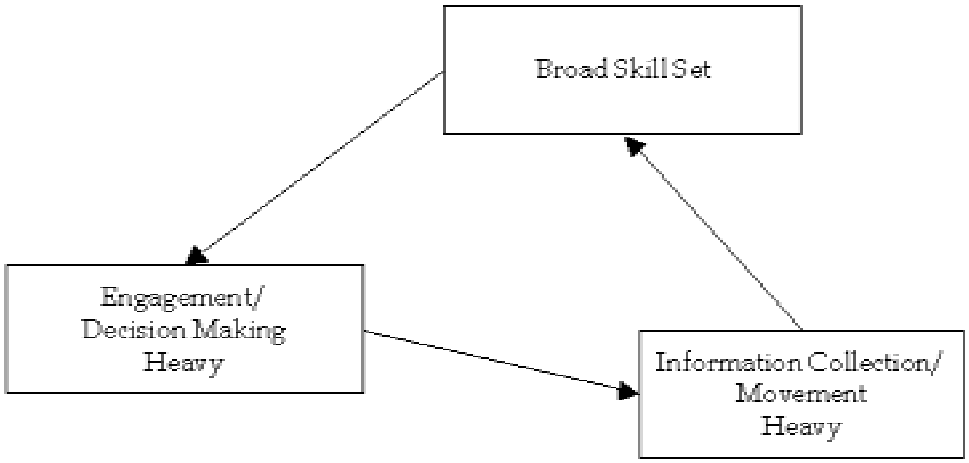


*Figure 11 - Condensed Cyclic Countering*

## 3.4 Blockage

### 3.4.1 General Observations

Up to this stage the scenarios have been played out on an empty battlefield. Therefore, there have been no environmental constraints on movement and observation. However, such capabilities are impeded by physical barriers and so, the effectiveness of any tactics where these are important may be compromised. As such, all scenarios already played out were repeated with a simple blockage pattern added (see Figure 5). Given our knowledge from the unconstrained scenarios, these blockage scenarios were not analysed in the same detail.

In general, the nature of the blockage seems to create a focal area for the forces to fight over. This focal area is the space between the two centre buildings on the map. If a force controls the focal area with sufficient mass, it tends to defeat its opponent. However, if it commits forces piecemeal towards this area the force is defeated rather easily.

### 3.4.2 Base Tactic Results

Table 15 shows the performance of the base tactics when blockage is placed on the terrain map, and includes a column to examine the difference in results between non-blockage and blockage situations. This column is possible because we can make some comparisons to Table 5, the original base tactics results, and is calculated by subtracting the casualty difference found in the original scenario from its blockage counterpart. The first thing of note is that all the tactics except for Better Firepower perform better when blockage is present. This is consistent with the Lanchester model, where, as force sizes decrease, firepower advantages become less apparent. However, other analysis [12] using a different form of ABD suggests otherwise.

Three tactics, namely Sight En – Chase, Sight En – Envelopment, and Slow down on contact, perform particularly well. Sight En – Chase seems to perform well because it aggressively moves into the previously described focal area, establishing overwhelming superiority in this area. In contrast, the other two tactics tend to hang outside the focal area, performing well against a red force that does not commit enough mass to attack there.

*Table 15 - Base Tactics Results when inhibited by blockage*

| BtID | Tactics | Blue Casualties | Red Casualties | Casualty Difference | Compared with non-blockage |
|---|---|---|---|---|---|
| | DEFAULT | 41.39 | 41.00 | -0.39 | -0.48 |
| 1 | Back off then attack | 28.52 | 49.02 | 20.50 | 3.01 |
| 2 | Better Firepower (10%) | 38.98 | 43.64 | 4.66 | -2.98 |
| 3 | Combat Advantage (Take 2) | 35.88 | 46.38 | 10.50 | 4.81 |
| 4 | Re-org on Shot at - get Stealth | 40.22 | 41.88 | 1.66 | 1.86 |
| 5 | Retreat to friends when shot at | 19.91 | 48.56 | 28.65 | 3.25 |
| 6 | Sight En - Chase | 37.03 | 46.18 | 9.15 | 7.65 |
| 7 | Sight En - Cluster - Attack | 13.54 | 48.49 | 34.95 | 4.17 |
| 8 | Sight En - Envelopment | 38.49 | 44.85 | 6.36 | 9.80 |
| 9 | Sight En - Flanking | 33.68 | 46.32 | 12.65 | 5.12 |
| 10 | Slow down on contact | 27.53 | 49.18 | 21.66 | 11.66 |
| 11 | Stealthier when shooting | 38.77 | 43.19 | 4.42 | 2.55 |

### 3.4.3 Combined Tactics Results

Combined tactics results with blockage introduced are displayed in Appendix D. Due to the increased performance of the base tactics with introduced blockage, the expected performance of the combined tactics also increases. We then begin approaching a limit of how well a force can perform, as increasing levels of overmatch produce lower payoff results. This limit is not reflected in the prediction method, and subsequently we see that most of the combined tactics perform below expectations.

Unlike the original combined tactics, this data set has no distinct outliers, the distribution of results being more uniform. A Combination Matrix was computed and is shown in Table 16.

*Table 16 - Combination Matrix for Blockage Results*

| | ENG | IC | DM | MOV |
|---|---|---|---|---|
| PRO | 1.581 | -1.697 | -0.505 | -7.325 |
| MOV | -1.537 | -15.581 | -23.457 | |
| DM | 0.232 | -4.995 | | |
| IC | -0.740 | | | |

Movement combines quite badly with most other tactics, figuring in the three worst performing skill combinations (IC/MOV, DM/MOV, PRO/MOV). This is consistent with the theory of urban terrain breaking up a force's cohesion and organisation. In contrast, Engagement and Protection perform relatively well, maintaining a fairly linear trend when other combinations under-perform. Engagement and Protection have been previously shown in this paper to have these linear characteristics but it is interesting to note that they hold firm for the blockage scenarios as well, despite the general under-performance present.

### 3.4.4 Single Red Tactic Playoff Results

Single red tactic playoff results with blockage introduced are displayed in Appendix E. Note the skill weighting columns are not present, as they are already covered in Appendix B. Instead of analysing individual scenarios, we will move straight to the Countering Graph for this section. This is displayed in Figure 12.

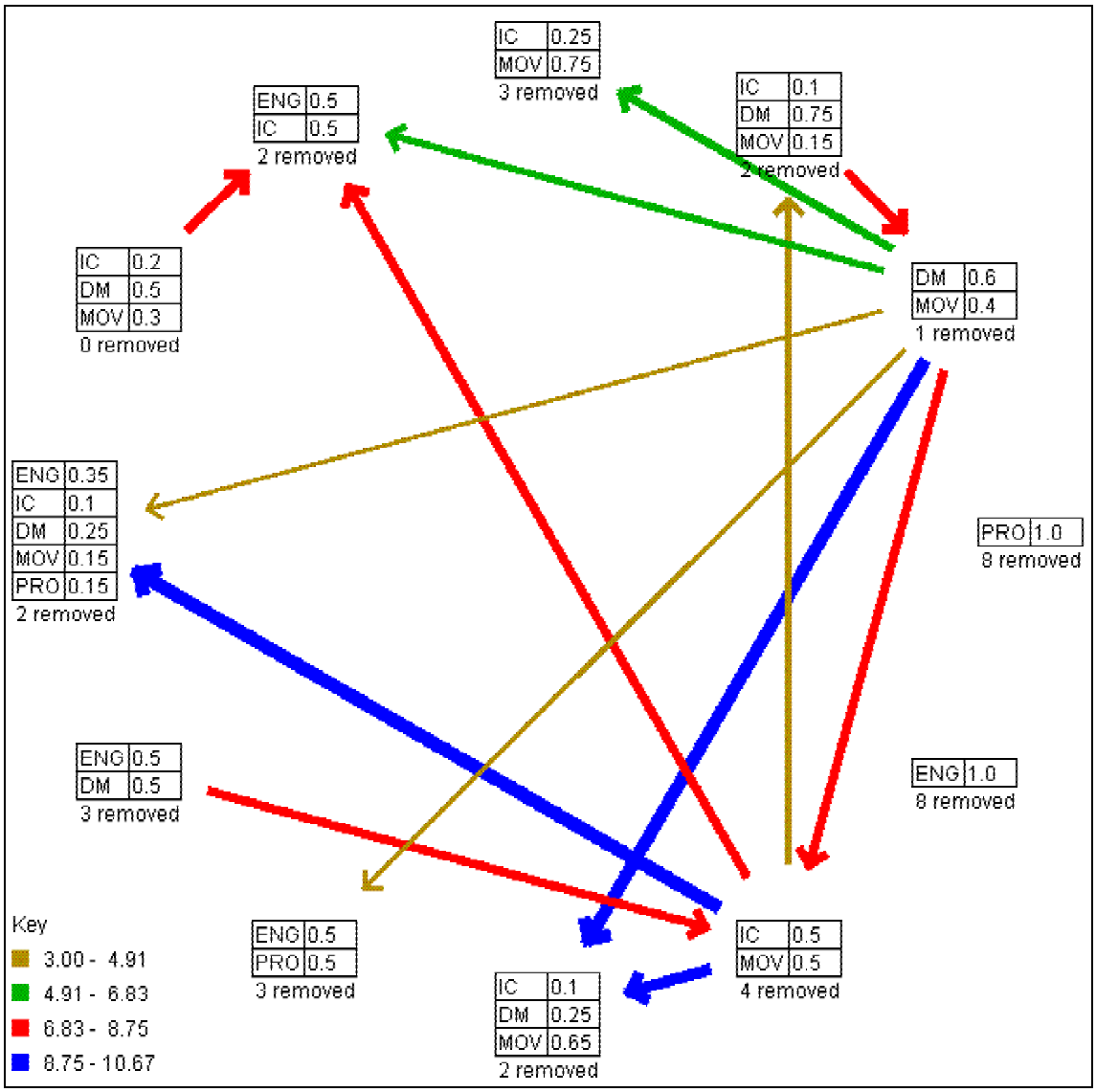


*Figure 12 - Countering Graph for Single Red Tactic Playoffs with Blockage Introduced*

Insights from Figure 12 are listed below.

- In comparison with Figure 8 (the non-blockage counterpart), Figure 12 is much flatter, with the largest link on the graph only 10.67, as compared to 24.13 in Figure 8. This is mostly due to the lack of performance of Movement based tactics observed in section 3.4.3. Inhibited by the terrain, these tactics lose their offensive edge.
- Once again, Engagement and Protection maintain their linear effect on the battlefield, indicating they remain largely unaffected by terrain.
- There appear to be no significant reverses in comparison to Figure 8. While many skill sets had their advantage diminished, at no time did the blockage cause a side to lose a battle they would normally win without blockage.

### 3.4.5 Combined Red Tactic Playoff Results

Combined red tactic playoff results with blockage introduced are displayed in Appendix F. Note the skill weighting columns are not present, as they are already covered in Appendix C. The Countering Graph is displayed in Figure 13.

Insights from Figure 13 are listed below:

- Tactics strong in Engagement and Decision Making remain dominant over tactics heavy in Information Collection and Movement. However, they lose the cyclic relationship described in section 3.3.2.1 with the broad skill set.
- In relation to the above point, the broad skill set of (ENG 0.35, IC 0.1, DM 0.25, MOV 0.15, PRO 0.15) loses its non-linearity seen when not using blockage.
- The tactic of (ENG 0.35/MOV 0.5/PRO 0.15) loses its dominance over all other tactics. In fact, with blockage introduced, it wins only one battle.
- Tactics heavy in Decision Making perform better with blockage introduced. The improvement isn't particularly large, but it is noticeable.
- The tactic (IC 0.1/DM 0.25/MOV 0.65) suffers two very large defeats in comparison to expectations, in both cases against Decision Making heavy tactics. However, it does perform better against the now weak (ENG 0.35/MOV 0.5/PRO 0.15).
- Movement in general is less effective. There are few cases of Movement heavy tactics defeating other tactics not containing Movement.

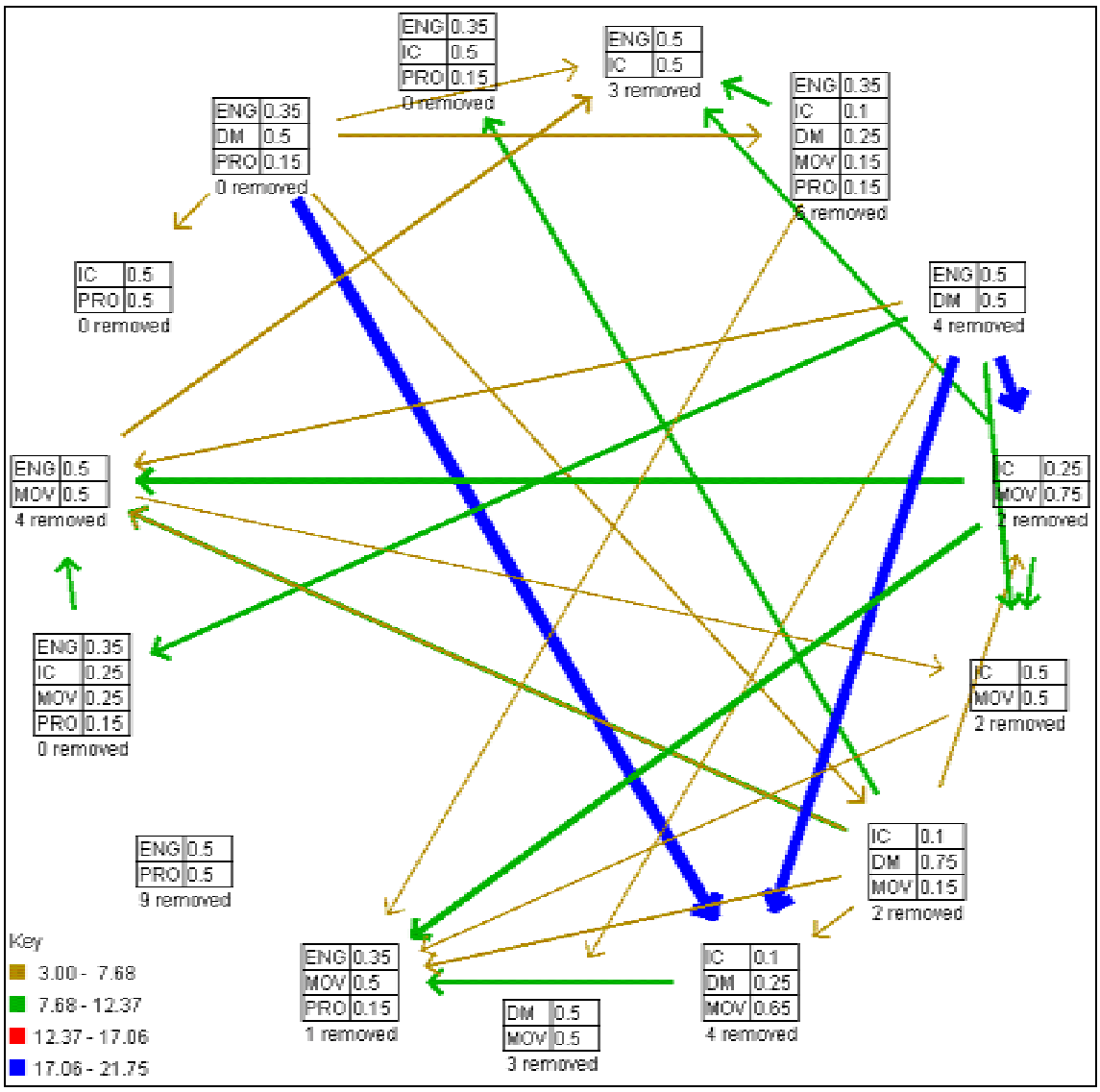


*Figure 13 - Countering Graph for Combined Red Tactic Playoffs with Blockage Introduced*

# 4. Discussion

## 4.1 Insights and Observations

This study has employed MANA to provide insight as to the relative worth of AAAS core skills by creating, combining and playing off a range of military tactics. After performing an extensive study across a large number of scenarios, many insights have emerged and are summarised here. These provide a firm basis for understanding the potential capability of a conceptual future force defined in terms of the AAAS construct.

The combination of Decision Making and Movement was identified to be a 'high risk' option. We determined this combination to be high risk because of the large number of non-linear results, both in favour and against this combination. However, this trend is not backed up by Figure 9, where the results involving this combination conform more closely to expectations. In this area we can draw parallels to manoeuvre warfare, which is an inherently high risk operation.

Engagement and Protection, both by themselves and in combination with each other, provide no significant positive or negative high-payoff on a force. This trend is present throughout the study, including with blockage introduced. This is traceable back to the AAAS, which surmises that most of the more obvious improvements in Engagement and Protection (weapon lethality, armour protection levels) provide only incremental improvements to a force [4].

Engagement and Information Collection do not combine well when played against other tactics. This feature is present throughout all the types of scenarios run. In addition, Engagement and Movement also combine badly against other tactics, though this combination was only tested in the combined red tactic scenarios. These two combinations seem to be areas less worthy of consideration when contemplating a future force structure.

Tactics heavy in Decision Making tend to have a mitigating effect on battles. These tactics do not often suffer catastrophic losses. This is an exception to the noted unpredictability of Movement and Decision Making in combination. It appears that while Decision Making in heavy amounts (> 0.5) helps forces not lose battles, in insufficient quantities its effectiveness decreases markedly. Interestingly, Decision Making heavy forces fighting against each other can have unpredictable results, suggesting the effectiveness of Decision Making is heavily dependant on the context in which it is used.

Without blockage, the combination of Engagement, Movement and Protection defeated all other tactics in the combined red tactic playoffs. However, once blockage was

introduced this combination degraded to the point of being one of the worst combinations. As was shown, and would be expected, on its own Movement suffers immensely from the introduction of blockage. This is shown in the difference between Table 9 and Table 16. The lack of any dominating Movement tactics in Figure 13 supports this. So since Engagement and Protection have been shown to have largely linear effects, it follows that this weakening is due to the under-performance of Movement once blockage is introduced.

A cyclic countering effect, or 'rock-paper-scissors' effect was noted in section 3.3.2.1, whereby a broad skill set was defeating Engagement/Decision Making, which defeated Information Collection/Movement, which in turn defeated the broad skill set. This effect was not present in the blockage scenarios, mostly due to the broad skill set attaining a linear performance structure in these scenarios.

## 4.2 Future Directions

This research program is relatively new. The study presented here only scratches the surface of what can be analysed. Certainly, the areas of Communications and Sustainment were not looked at in this study, as these core skills require more complex forces than the ones we used for this study. In theory it is possible for MANA to provide the ability to simulate these skills, however, scenarios would have to be more tailored towards bringing these core skills to bear.

This requirement to increase complexity parallels our desire to explore more complex forces. The first iteration of increasing the complexity of the forces should be adding agents possessing long-range burst weapons. With a structure such as this, Communications can be brought into play easily. In addition, there are many more possibilities for tactics to be employed to make use of these weapons. Another force structure to look at would be the introduction of small numbers of soldiers possessing superior abilities. This structure could also be used to explore the technology/ structure/doctrine versus mass paradigm.

Enhancements can be made to the analysis methods used. Analysis methods used in this study such as the Countering Graph and Combination Matrix need verification outside of this study. Further work needs to be undertaken focusing on the distribution of results from the replications of the scenarios, especially with respect to drawing parallels to Lanchester models. Also, if more complex force structures are introduced as is suggested above, the analysis methods must also increase in complexity.

The Counter Graphs displayed in this study were all computed after all scenarios were completed. In future, Counter Graphs could be used interactively to guide the user on where to proceed in the problem space. In a study such as this where the number of possible combinations of tactics can reach the thousands, such a tool could greatly speed up the investigation process, showing areas of possible interest and areas where more scenarios need to be played to solidify analysis.

Future studies could also take another approach to the core skills/tactics mapping, where core skills become enablers to various available tactics, so as they reach thresholds of competency in certain core skills, they gain abilities consistent with these core skills. This method would enable direct manipulation of core skills, allowing for a true parametric study to be conducted. It may also be possible to incorporate human factors into these enablers, such as morale, fear and aggression.

Finally, this area of work can be extended to include Game Theory, where the results from studies such as this populate a payoff matrix when choosing strategies.

## 4.3 Emergence

An aim behind this experiment was to explore the problem space in search of any emergent properties that may exist. Note that the emergent properties themselves were not of particular interest. Instead, we looked for the impact these properties had on the effectiveness of various core skill combinations. Some of the tactics used, particularly those that reacted to an enemy presence, were adaptive to situations presented to them. The main exponent of this adaptiveness was the Combat Advantage tactic, which had a mitigating effect on nearly all the tactics it faced.

In searching for emergent properties, one must be wary of the difference between true emergence and faults or antagonisms within the system. Some tactics, particularly the Combat Advantage base tactic, are naturally responsive to enemy actions and provide a sufficient basis for emergence to occur. In other cases, the cause for an anomaly is more difficult to discern. For example, when Envelopment faces Flanking, the Envelopment manoeuvre fails because it attempts to attack an enemy that it expects to be ahead of it. Can this be attributed to a lack of flexibility in the particular skill set Envelopment represents, or should blame be shifted towards the scenario design?

In essence, it is possible for tactics to be defined too rigidly to handle certain situations. It therefore may be necessary to define tactics on a much simpler and broader basis, to increase their adaptiveness by giving the tactics looser rules to abide by. The danger with this approach is that as tactics become broader, they may lose their relevance to the core skills we are trying to simulate. At this end of the spectrum, we give the units behaviour to follow, rather than a proper military tactic, and so end up with seemingly random combinations of behaviours providing various results. Therefore we must balance the research between designing for emergence and maintaining relevance to our goal of determining the relationships between core skills. The work presented here leans towards the latter and provides an excellent building block for future investigation into this area.

# 5. Conclusion

This study aimed to investigate the synergies and antagonisms of the AAAS core skills using MANA by building complex forces with varied skill sets and playing them against each other. In this it was successful, identifying several trends and relationships that can be directions for further study. Also, tools and methods such as the Countering Graph were developed that will greatly assist future research. This study is a gateway for future research in this area.

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# Appendix A: Combined Tactics Results

*Table 17 - Combined Tactics Results*

| ID Information | | | Attrition Information | | | | | Tactic Skill Weightings | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CtID | Tactic 1 BtID | Tactic 2 BtID | Blue Casualties | Red Casualties | Casualty Difference | Expected Difference | Performance | ENG | IC | COM | DM | SUS | MOV | PRO |
| 1 | 11 | 2 | 34.23 | 44.30 | 10.07 | 9.51 | 0.55 | 0.85 | 0 | 0 | 0 | 0 | 0 | 0.15 |
| 2 | 1 | 2 | 27.40 | 49.47 | 22.06 | 25.14 | -3.08 | 0.5 | 0 | 0 | 0 | 0 | 0.5 | 0 |
| 3 | 1 | 3 | 29.73 | 49.00 | 19.27 | 23.19 | -3.92 | 0 | 0 | 0 | 0.5 | 0 | 0.5 | 0 |
| 4 | 2 | 3 | 35.20 | 47.24 | 12.04 | 13.34 | -1.30 | 0.5 | 0 | 0 | 0.5 | 0 | 0 | 0 |
| 5 | 4 | 9 | 35.84 | 44.42 | 8.58 | 7.33 | 1.25 | 0 | 0.25 | 0 | 0 | 0 | 0.25 | 0.5 |
| 6 | 4 | 10 | 34.86 | 43.96 | 9.11 | 9.79 | -0.68 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0.5 |
| 7 | 9 | 11 | 36.51 | 44.36 | 7.85 | 9.40 | -1.55 | 0.35 | 0.25 | 0 | 0 | 0 | 0.25 | 0.15 |
| 8 | 2 | 8 | 38.92 | 43.41 | 4.49 | 4.20 | 0.29 | 0.5 | 0.1 | 0 | 0.25 | 0 | 0.15 | 0 |
| 9 | 8 | 11 | 41.59 | 41.31 | -0.28 | -1.57 | 1.29 | 0.35 | 0.1 | 0 | 0.25 | 0 | 0.15 | 0.15 |
| 10 | 3 | 11 | 32.40 | 49.18 | 16.78 | 7.56 | 9.22 | 0.35 | 0 | 0 | 0.5 | 0 | 0 | 0.15 |
| 11 | 3 | 9 | 34.74 | 45.26 | 10.52 | 13.23 | -2.70 | 0 | 0.25 | 0 | 0.5 | 0 | 0.25 | 0 |
| 12 | 2 | 4 | 35.48 | 43.45 | 7.97 | 7.44 | 0.53 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0.5 |
| 13 | 3 | 10 | 35.09 | 46.23 | 11.14 | 15.69 | -4.54 | 0 | 0 | 0 | 0.5 | 0 | 0.5 | 0 |
| 14 | 3 | 8 | 36.04 | 46.26 | 10.22 | 2.25 | 7.97 | 0 | 0.1 | 0 | 0.75 | 0 | 0.15 | 0 |
| 15 | 3 | 4 | 38.34 | 45.11 | 6.77 | 5.50 | 1.27 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0.5 |
| 16 | 2 | 6 | 36.34 | 44.72 | 8.38 | 9.15 | -0.76 | 0.5 | 0.5 | 0 | 0 | 0 | 0 | 0 |
| 17 | 2 | 9 | 33.00 | 46.13 | 13.13 | 15.17 | -2.05 | 0.5 | 0.25 | 0 | 0 | 0 | 0.25 | 0 |
| 18 | 2 | 10 | 30.61 | 47.33 | 16.72 | 17.63 | -0.91 | 0.5 | 0 | 0 | 0 | 0 | 0.5 | 0 |
| 19 | 4 | 6 | 40.12 | 41.15 | 1.03 | 1.30 | -0.27 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0.5 |
| 20 | 6 | 10 | 35.04 | 45.79 | 10.75 | 11.49 | -0.75 | 0 | 0.5 | 0 | 0 | 0 | 0.5 | 0 |
| 21 | 6 | 11 | 39.74 | 42.03 | 2.29 | 3.37 | -1.08 | 0.35 | 0.5 | 0 | 0 | 0 | 0 | 0.15 |
| 22 | 8 | 10 | 31.43 | 48.08 | 16.66 | 6.55 | 10.11 | 0 | 0.1 | 0 | 0.25 | 0 | 0.65 | 0 |
| 23 | 9 | 10 | 28.13 | 48.12 | 20.00 | 17.52 | 2.48 | 0 | 0.25 | 0 | 0 | 0 | 0.75 | 0 |
| 24 | 10 | 11 | 33.42 | 45.80 | 12.39 | 11.86 | 0.53 | 0.35 | 0 | 0 | 0 | 0 | 0.5 | 0.15 |

# Appendix B: 2v1 Playoff Results

*Table 18 – 2v1Playoff Results*

| | Blue Tactic Information | | | | | | Red Tactic Information | | | | | | Attrition Information | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ps ID | Blue CtID | ENG | IC | DM | MOV | PRO | Red BtID | ENG | IC | DM | MOV | PRO | Blue Casualties | Red Casualties | Casualty Difference | Expected Difference | Performance |
| 1 | 22 | 0 | 0.1 | 0.25 | 0.65 | 0 | 9 | 0 | 0.5 | 0 | 0.5 | 0 | 47.52 | 32.50 | -15.02 | 9.12 | -24.14 |
| 2 | 22 | 0 | 0.1 | 0.25 | 0.65 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 34.85 | 46.56 | 11.71 | 9.01 | 2.70 |
| 3 | 22 | 0 | 0.1 | 0.25 | 0.65 | 0 | 4 | 0 | 0 | 0 | 0 | 1 | 31.59 | 47.70 | 16.10 | 16.85 | -0.75 |
| 4 | 22 | 0 | 0.1 | 0.25 | 0.65 | 0 | 5 | 0 | 0 | 0.6 | 0.4 | 0 | 48.50 | 26.00 | -22.50 | -8.75 | -13.75 |
| 5 | 14 | 0 | 0.1 | 0.75 | 0.15 | 0 | 9 | 0 | 0.5 | 0 | 0.5 | 0 | 37.93 | 37.79 | -0.14 | 2.69 | -2.83 |
| 6 | 14 | 0 | 0.1 | 0.75 | 0.15 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 38.49 | 44.25 | 5.76 | 2.58 | 3.18 |
| 7 | 14 | 0 | 0.1 | 0.75 | 0.15 | 0 | 4 | 0 | 0 | 0 | 0 | 1 | 37.82 | 44.52 | 6.70 | 10.42 | -3.72 |
| 8 | 14 | 0 | 0.1 | 0.75 | 0.15 | 0 | 5 | 0 | 0 | 0.6 | 0.4 | 0 | 31.08 | 33.70 | 2.61 | -15.19 | 17.80 |
| 9 | 23 | 0 | 0.25 | 0 | 0.75 | 0 | 9 | 0 | 0.5 | 0 | 0.5 | 0 | 36.75 | 45.15 | 8.40 | 12.47 | -4.06 |
| 10 | 23 | 0 | 0.25 | 0 | 0.75 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 31.05 | 47.40 | 16.34 | 12.36 | 3.99 |
| 11 | 23 | 0 | 0.25 | 0 | 0.75 | 0 | 4 | 0 | 0 | 0 | 0 | 1 | 28.99 | 47.98 | 18.99 | 20.20 | -1.21 |
| 12 | 23 | 0 | 0.25 | 0 | 0.75 | 0 | 5 | 0 | 0 | 0.6 | 0.4 | 0 | 48.74 | 27.23 | -21.51 | -5.41 | -16.10 |
| 13 | 16 | 0.5 | 0.5 | 0 | 0 | 0 | 9 | 0 | 0.5 | 0 | 0.5 | 0 | 45.49 | 35.44 | -10.05 | 0.85 | -10.90 |
| 14 | 16 | 0.5 | 0.5 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 40.42 | 41.87 | 1.46 | 0.74 | 0.71 |
| 15 | 16 | 0.5 | 0.5 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 1 | 36.25 | 44.91 | 8.66 | 8.58 | 0.08 |
| 16 | 16 | 0.5 | 0.5 | 0 | 0 | 0 | 5 | 0 | 0 | 0.6 | 0.4 | 0 | 48.93 | 27.03 | -21.90 | -17.02 | -4.88 |
| 17 | 16 | 0.5 | 0.5 | 0 | 0 | 0 | 8 | 0 | 0.2 | 0.5 | 0.3 | 0 | 40.47 | 42.23 | 1.76 | 11.82 | -10.07 |
| 18 | 20 | 0 | 0.5 | 0 | 0.5 | 0 | 9 | 0 | 0.5 | 0 | 0.5 | 0 | 38.45 | 43.89 | 5.44 | 3.21 | 2.23 |
| 19 | 20 | 0 | 0.5 | 0 | 0.5 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 39.65 | 42.52 | 2.86 | 3.10 | -0.24 |
| 20 | 20 | 0 | 0.5 | 0 | 0.5 | 0 | 4 | 0 | 0 | 0 | 0 | 1 | 34.94 | 45.82 | 10.88 | 10.94 | -0.06 |
| 21 | 20 | 0 | 0.5 | 0 | 0.5 | 0 | 5 | 0 | 0 | 0.6 | 0.4 | 0 | 49.82 | 26.36 | -23.45 | -14.66 | -8.79 |
| 22 | 9 | 0.35 | 0.1 | 0.25 | 0.15 | 0.15 | 9 | 0 | 0.5 | 0 | 0.5 | 0 | 49.21 | 19.88 | -29.33 | -7.81 | -21.52 |
| 23 | 9 | 0.35 | 0.1 | 0.25 | 0.15 | 0.15 | 2 | 1 | 0 | 0 | 0 | 0 | 44.97 | 36.66 | -8.31 | -7.92 | -0.39 |
| 24 | 9 | 0.35 | 0.1 | 0.25 | 0.15 | 0.15 | 4 | 0 | 0 | 0 | 0 | 1 | 42.41 | 39.70 | -2.71 | -0.08 | -2.63 |
| 25 | 9 | 0.35 | 0.1 | 0.25 | 0.15 | 0.15 | 5 | 0 | 0 | 0.6 | 0.4 | 0 | 48.46 | 20.83 | -27.63 | -25.69 | -1.95 |

| | Blue Tactic Information | | | | | | Red Tactic Information | | | | | | Attrition Information | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ps ID | Blue CtID | ENG | IC | DM | MOV | PRO | Red BtID | ENG | IC | DM | MOV | PRO | Blue Casualties | Red Casualties | Casualty Difference | Expected Difference | Performance |
| 26 | 4 | 0.5 | 0 | 0.5 | 0 | 0 | 9 | 0 | 0.5 | 0 | 0.5 | 0 | 39.22 | 46.48 | 7.27 | 4.51 | 2.76 |
| 27 | 4 | 0.5 | 0 | 0.5 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 38.75 | 45.62 | 6.87 | 4.40 | 2.47 |
| 28 | 4 | 0.5 | 0 | 0.5 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 1 | 35.59 | 46.73 | 11.14 | 12.24 | -1.10 |
| 29 | 4 | 0.5 | 0 | 0.5 | 0 | 0 | 5 | 0 | 0 | 0.6 | 0.4 | 0 | 39.29 | 43.22 | 3.93 | -13.37 | 17.29 |
| 30 | 12 | 0.5 | 0 | 0 | 0 | 0.5 | 9 | 0 | 0.5 | 0 | 0.5 | 0 | 41.63 | 40.68 | -0.95 | 0.44 | -1.39 |
| 31 | 12 | 0.5 | 0 | 0 | 0 | 0.5 | 2 | 1 | 0 | 0 | 0 | 0 | 39.55 | 40.28 | 0.73 | 0.33 | 0.40 |
| 32 | 12 | 0.5 | 0 | 0 | 0 | 0.5 | 4 | 0 | 0 | 0 | 0 | 1 | 35.83 | 43.36 | 7.53 | 8.17 | -0.64 |
| 33 | 12 | 0.5 | 0 | 0 | 0 | 0.5 | 5 | 0 | 0 | 0.6 | 0.4 | 0 | 47.82 | 26.71 | -21.10 | -17.43 | -3.67 |

# Appendix C: 2v2 Playoff Results

*Table 19 – 2v2 Playoff Results*

| | Blue Tactic Information | | | | | | Red Tactic Information | | | | | | Attrition Information | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pc ID | Blue CtID | ENG | IC | DM | MOV | PRO | Red CtID | ENG | IC | DM | MOV | PRO | Blue Casualties | Red Casualties | Casualty Difference | Expected Difference | Performance |
| 1 | 3 | 0 | 0 | 0.5 | 0.5 | 0 | 22 | 0 | 0.1 | 0.25 | 0.65 | 0 | 43.36 | 44.64 | 1.28 | 2.62 | -1.34 |
| 2 | 14 | 0 | 0.1 | 0.75 | 0.15 | 0 | 22 | 0 | 0.1 | 0.25 | 0.65 | 0 | 43.66 | 37.63 | -6.02 | -6.44 | 0.41 |
| 3 | 20 | 0 | 0.5 | 0 | 0.5 | 0 | 23 | 0 | 0.25 | 0 | 0.75 | 0 | 43.56 | 40.44 | -3.12 | -9.25 | 6.13 |
| 4 | 4 | 0.5 | 0 | 0.5 | 0 | 0 | 9 | 0.35 | 0.1 | 0.25 | 0.15 | 0.15 | 43.01 | 39.74 | -3.27 | 12.32 | -15.59 |
| 5 | 16 | 0.5 | 0.5 | 0 | 0 | 0 | 9 | 0.35 | 0.1 | 0.25 | 0.15 | 0.15 | 41.96 | 40.87 | -1.09 | 8.66 | -9.75 |
| 6 | 16 | 0.5 | 0.5 | 0 | 0 | 0 | 23 | 0 | 0.25 | 0 | 0.75 | 0 | 48.86 | 29.04 | -19.82 | -11.61 | -8.20 |
| 7 | 14 | 0 | 0.1 | 0.75 | 0.15 | 0 | 23 | 0 | 0.25 | 0 | 0.75 | 0 | 37.41 | 35.35 | -2.05 | -9.78 | 7.72 |
| 8 | 14 | 0 | 0.1 | 0.75 | 0.15 | 0 | 21 | 0.35 | 0.5 | 0 | 0 | 0.15 | 38.91 | 44.94 | 6.02 | 7.93 | -1.91 |
| 9 | 10 | 0.35 | 0 | 0.5 | 0 | 0.15 | 19 | 0 | 0.5 | 0 | 0 | 0.5 | 32.55 | 49.09 | 16.54 | 15.75 | 0.79 |
| 10 | 2 | 0.5 | 0 | 0 | 0.5 | 0 | 22 | 0 | 0.1 | 0.25 | 0.65 | 0 | 41.95 | 44.65 | 2.71 | 5.41 | -2.70 |
| 11 | 2 | 0.5 | 0 | 0 | 0.5 | 0 | 7 | 0.35 | 0.25 | 0 | 0.25 | 0.15 | 42.46 | 42.68 | 0.22 | 14.22 | -13.99 |
| 12 | 18 | 0.5 | 0 | 0 | 0.5 | 0 | 14 | 0 | 0.1 | 0.75 | 0.15 | 0 | 39.87 | 40.75 | 0.88 | 6.50 | -5.62 |
| 13 | 14 | 0 | 0.1 | 0.75 | 0.15 | 0 | 10 | 0.35 | 0 | 0.5 | 0 | 0.15 | 45.02 | 40.81 | -4.21 | -6.56 | 2.35 |
| 14 | 12 | 0.5 | 0 | 0 | 0 | 0.5 | 14 | 0 | 0.1 | 0.75 | 0.15 | 0 | 41.94 | 40.76 | -1.18 | -2.25 | 1.06 |
| 15 | 12 | 0.5 | 0 | 0 | 0 | 0.5 | 16 | 0.5 | 0.5 | 0 | 0 | 0 | 41.01 | 40.92 | -0.08 | -0.41 | 0.33 |
| 16 | 22 | 0 | 0.1 | 0.25 | 0.65 | 0 | 9 | 0.35 | 0.1 | 0.25 | 0.15 | 0.15 | 25.63 | 49.59 | 23.97 | 16.93 | 7.04 |
| 17 | 9 | 0.35 | 0.1 | 0.25 | 0.15 | 0.15 | 23 | 0 | 0.25 | 0 | 0.75 | 0 | 49.43 | 19.08 | -30.35 | -20.28 | -10.07 |
| 18 | 20 | 0 | 0.5 | 0 | 0.5 | 0 | 9 | 0.35 | 0.1 | 0.25 | 0.15 | 0.15 | 30.66 | 47.73 | 17.06 | 11.02 | 6.04 |
| 19 | 10 | 0.35 | 0 | 0.5 | 0 | 0.15 | 22 | 0 | 0.1 | 0.25 | 0.65 | 0 | 41.39 | 47.58 | 6.18 | 0.13 | 6.06 |
| 20 | 10 | 0.35 | 0 | 0.5 | 0 | 0.15 | 9 | 0.35 | 0.1 | 0.25 | 0.15 | 0.15 | 43.14 | 40.31 | -2.83 | 17.06 | -19.89 |
| 21 | 12 | 0.5 | 0 | 0 | 0 | 0.5 | 20 | 0 | 0.5 | 0 | 0.5 | 0 | 42.23 | 40.31 | -1.92 | -2.77 | 0.85 |
| 22 | 16 | 0.5 | 0.5 | 0 | 0 | 0 | 10 | 0.35 | 0 | 0.5 | 0 | 0.15 | 49.03 | 34.72 | -14.30 | -8.40 | -5.91 |
| 23 | 4 | 0.5 | 0 | 0.5 | 0 | 0 | 7 | 0.35 | 0.25 | 0 | 0.25 | 0.15 | 39.67 | 46.38 | 6.71 | 4.19 | 2.51 |
| 24 | 2 | 0.5 | 0 | 0 | 0.5 | 0 | 4 | 0.5 | 0 | 0.5 | 0 | 0 | 41.03 | 45.69 | 4.66 | 10.02 | -5.36 |
| 25 | 2 | 0.5 | 0 | 0 | 0.5 | 0 | 3 | 0 | 0 | 0.5 | 0.5 | 0 | 42.89 | 43.13 | 0.23 | 2.79 | -2.55 |

| | Blue Tactic Information | | | | | | Red Tactic Information | | | | | | Attrition Information | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pc ID | Blue CtID | ENG | IC | DM | MOV | PRO | Red CtID | ENG | IC | DM | MOV | PRO | Blue Casualties | Red Casualties | Casualty Difference | Expected Difference | Performance |
| 26 | 3 | 0 | 0 | 0.5 | 0.5 | 0 | 4 | 0.5 | 0 | 0.5 | 0 | 0 | 41.94 | 45.52 | 3.57 | 7.23 | -3.66 |
| 27 | 2 | 0.5 | 0 | 0 | 0.5 | 0 | 12 | 0.5 | 0 | 0 | 0 | 0.5 | 32.46 | 48.06 | 15.60 | 14.09 | 1.51 |
| 28 | 3 | 0 | 0 | 0.5 | 0.5 | 0 | 12 | 0.5 | 0 | 0 | 0 | 0.5 | 34.28 | 47.81 | 13.53 | 11.30 | 2.23 |
| 29 | 12 | 0.5 | 0 | 0 | 0 | 0.5 | 4 | 0.5 | 0 | 0.5 | 0 | 0 | 44.19 | 39.73 | -4.46 | -4.07 | -0.39 |
| 30 | 4 | 0.5 | 0 | 0.5 | 0 | 0 | 23 | 0 | 0.25 | 0 | 0.75 | 0 | 42.01 | 46.39 | 4.38 | -7.96 | 12.34 |
| 31 | 2 | 0.5 | 0 | 0 | 0.5 | 0 | 23 | 0 | 0.25 | 0 | 0.75 | 0 | 48.88 | 30.44 | -18.44 | 2.06 | -20.51 |
| 32 | 2 | 0.5 | 0 | 0 | 0.5 | 0 | 14 | 0 | 0.1 | 0.75 | 0.15 | 0 | 39.34 | 41.79 | 2.45 | 11.84 | -9.39 |
| 33 | 2 | 0.5 | 0 | 0 | 0.5 | 0 | 20 | 0 | 0.5 | 0 | 0.5 | 0 | 37.84 | 46.03 | 8.19 | 11.32 | -3.13 |
| 34 | 2 | 0.5 | 0 | 0 | 0.5 | 0 | 16 | 0.5 | 0.5 | 0 | 0 | 0 | 29.18 | 49.30 | 20.12 | 13.68 | 6.44 |
| 35 | 2 | 0.5 | 0 | 0 | 0.5 | 0 | 9 | 0.35 | 0.1 | 0.25 | 0.15 | 0.15 | 33.37 | 48.47 | 15.10 | 22.34 | -7.24 |
| 36 | 4 | 0.5 | 0 | 0.5 | 0 | 0 | 22 | 0 | 0.1 | 0.25 | 0.65 | 0 | 44.56 | 44.20 | -0.36 | -4.62 | 4.25 |
| 37 | 4 | 0.5 | 0 | 0.5 | 0 | 0 | 14 | 0 | 0.1 | 0.75 | 0.15 | 0 | 44.12 | 41.40 | -2.71 | 1.82 | -4.53 |
| 38 | 4 | 0.5 | 0 | 0.5 | 0 | 0 | 20 | 0 | 0.5 | 0 | 0.5 | 0 | 38.05 | 48.24 | 10.20 | 1.30 | 8.90 |
| 39 | 16 | 0.5 | 0.5 | 0 | 0 | 0 | 4 | 0.5 | 0 | 0.5 | 0 | 0 | 46.36 | 38.70 | -7.66 | -3.66 | -4.00 |
| 40 | 12 | 0.5 | 0 | 0 | 0 | 0.5 | 22 | 0 | 0.1 | 0.25 | 0.65 | 0 | 45.94 | 36.12 | -9.82 | -8.68 | -1.14 |
| 41 | 12 | 0.5 | 0 | 0 | 0 | 0.5 | 23 | 0 | 0.25 | 0 | 0.75 | 0 | 46.75 | 32.15 | -14.60 | -12.02 | -2.58 |
| 42 | 12 | 0.5 | 0 | 0 | 0 | 0.5 | 9 | 0.35 | 0.1 | 0.25 | 0.15 | 0.15 | 35.71 | 45.86 | 10.15 | 8.25 | 1.90 |
| 43 | 22 | 0 | 0.1 | 0.25 | 0.65 | 0 | 24 | 0.35 | 0 | 0 | 0.5 | 0.15 | 46.35 | 35.14 | -11.21 | 4.27 | -15.48 |
| 44 | 14 | 0 | 0.1 | 0.75 | 0.15 | 0 | 24 | 0.35 | 0 | 0 | 0.5 | 0.15 | 42.46 | 32.84 | -9.62 | -2.17 | -7.46 |
| 45 | 23 | 0 | 0.25 | 0 | 0.75 | 0 | 24 | 0.35 | 0 | 0 | 0.5 | 0.15 | 44.11 | 39.11 | -5.00 | 7.61 | -12.61 |
| 46 | 20 | 0 | 0.5 | 0 | 0.5 | 0 | 24 | 0.35 | 0 | 0 | 0.5 | 0.15 | 42.95 | 39.64 | -3.31 | -1.64 | -1.67 |
| 47 | 16 | 0.5 | 0.5 | 0 | 0 | 0 | 24 | 0.35 | 0 | 0 | 0.5 | 0.15 | 44.01 | 37.51 | -6.51 | -4.00 | -2.50 |
| 48 | 9 | 0.35 | 0.1 | 0.25 | 0.15 | 0.15 | 24 | 0.35 | 0 | 0 | 0.5 | 0.15 | 49.23 | 24.81 | -24.42 | -12.66 | -11.75 |

# Appendix D: Combined Tactics Results – Blockage Introduced

*Table 20 - Combined Tactics Results - Blockage Introduced (skill weightings in Table 17)*

| ID Information | | | Attrition Information | | | | | |
|---|---|---|---|---|---|---|---|---|
| CtID | Tactic 1 BtID | Tactic 2 BtID | Blue Casualties | Red Casualties | Casualty Difference | Expected Difference | Difference of Difference | Compared with non-blockage |
| 1 | 11 | 2 | 35.11 | 46.20 | 11.09 | 9.09 | 2.00 | 1.45 |
| 2 | 1 | 2 | 24.56 | 49.68 | 25.12 | 25.17 | -0.05 | 3.03 |
| 3 | 1 | 3 | 27.85 | 49.11 | 21.27 | 31.00 | -9.74 | -5.82 |
| 4 | 2 | 3 | 32.90 | 48.17 | 15.27 | 15.16 | 0.10 | 1.40 |
| 5 | 4 | 9 | 33.19 | 46.36 | 13.17 | 14.30 | -1.13 | -2.38 |
| 6 | 4 | 10 | 30.40 | 47.79 | 17.39 | 23.31 | -5.92 | -5.24 |
| 7 | 9 | 11 | 32.35 | 46.72 | 14.37 | 17.07 | -2.70 | -1.15 |
| 8 | 2 | 8 | 34.37 | 46.99 | 12.62 | 11.02 | 1.60 | 1.32 |
| 9 | 8 | 11 | 37.02 | 46.02 | 9.00 | 10.78 | -1.78 | -3.07 |
| 10 | 3 | 11 | 33.03 | 47.94 | 14.91 | 14.92 | -0.01 | -9.23 |
| 11 | 3 | 9 | 30.47 | 47.10 | 16.63 | 23.15 | -6.52 | -3.82 |
| 12 | 2 | 4 | 37.16 | 44.45 | 7.29 | 6.32 | 0.97 | 0.44 |
| 13 | 3 | 10 | 25.54 | 49.71 | 24.17 | 32.16 | -7.99 | -3.44 |
| 14 | 3 | 8 | 35.23 | 46.93 | 11.71 | 16.86 | -5.15 | -13.12 |
| 15 | 3 | 4 | 34.76 | 46.60 | 11.83 | 12.16 | -0.32 | -1.59 |
| 16 | 2 | 6 | 34.16 | 47.76 | 13.61 | 13.82 | -0.21 | 0.55 |
| 17 | 2 | 9 | 29.26 | 47.83 | 18.57 | 17.31 | 1.26 | 3.31 |
| 18 | 2 | 10 | 24.21 | 49.62 | 25.41 | 26.32 | -0.91 | 0.00 |
| 19 | 4 | 6 | 35.81 | 46.26 | 10.45 | 10.81 | -0.36 | -0.08 |
| 20 | 6 | 10 | 25.40 | 49.59 | 24.20 | 30.81 | -6.61 | -5.86 |
| 21 | 6 | 11 | 34.55 | 46.76 | 12.21 | 13.58 | -1.37 | -0.28 |
| 22 | 8 | 10 | 23.80 | 49.57 | 25.78 | 28.01 | -2.24 | -12.34 |
| 23 | 9 | 10 | 20.69 | 49.53 | 28.84 | 34.30 | -5.46 | -7.93 |
| 24 | 10 | 11 | 24.86 | 49.44 | 24.58 | 26.08 | -1.50 | -2.03 |

# Appendix E: 2v1 Playoff Results – Blockage Introduced

*Table 21 – 2v1 Playoff Results - Blockage Introduced (skill weightings in Table 18)*

| ID Information | | | Attrition Information | | | | | |
|---|---|---|---|---|---|---|---|---|
| ID | Blue CtID | Red BtID | Blue Casualties | Red Casualties | Casualty Difference | Expected Difference | Difference of Difference | Compared with non-blockage |
| 1 | 22 | 9 | 40.89 | 45.04 | 4.15 | 13.13 | -8.98 | 15.16 |
| 2 | 22 | 2 | 27.20 | 48.98 | 21.78 | 21.11 | 0.66 | -2.03 |
| 3 | 22 | 4 | 24.95 | 49.40 | 24.45 | 24.12 | 0.33 | 1.08 |
| 4 | 22 | 5 | 46.69 | 33.70 | -13.00 | -2.88 | -10.12 | 3.63 |
| 5 | 14 | 9 | 42.15 | 36.48 | -5.68 | -0.94 | -4.74 | -1.90 |
| 6 | 14 | 2 | 38.53 | 44.74 | 6.21 | 7.04 | -0.84 | -4.02 |
| 7 | 14 | 4 | 37.44 | 45.20 | 7.75 | 10.05 | -2.30 | 1.42 |
| 8 | 14 | 5 | 39.93 | 30.37 | -9.56 | -16.95 | 7.39 | -10.41 |
| 9 | 23 | 9 | 31.67 | 48.47 | 16.80 | 16.20 | 0.61 | 4.67 |
| 10 | 23 | 2 | 23.97 | 49.09 | 25.12 | 24.18 | 0.94 | -3.05 |
| 11 | 23 | 4 | 21.61 | 49.47 | 27.86 | 27.19 | 0.67 | 1.88 |
| 12 | 23 | 5 | 44.49 | 38.03 | -6.46 | 0.19 | -6.66 | 9.45 |
| 13 | 16 | 9 | 44.65 | 38.52 | -6.13 | 0.96 | -7.09 | 3.81 |
| 14 | 16 | 2 | 37.21 | 46.21 | 9.00 | 8.94 | 0.06 | -0.66 |
| 15 | 16 | 4 | 34.14 | 47.80 | 13.66 | 11.95 | 1.71 | 1.64 |
| 16 | 16 | 5 | 48.83 | 28.20 | -20.64 | -15.05 | -5.59 | -0.71 |
| 17 | 16 | 8 | 42.20 | 42.03 | -0.17 | 7.25 | -7.42 | 2.65 |
| 18 | 20 | 9 | 38.27 | 44.00 | 5.73 | 11.55 | -5.82 | -8.04 |
| 19 | 20 | 2 | 29.32 | 49.09 | 19.77 | 19.53 | 0.23 | 0.47 |
| 20 | 20 | 4 | 26.19 | 49.58 | 23.39 | 22.54 | 0.85 | 0.91 |
| 21 | 20 | 5 | 46.03 | 34.54 | -11.50 | -4.46 | -7.04 | 1.75 |
| 22 | 9 | 9 | 48.04 | 33.72 | -14.32 | -3.64 | -10.68 | 10.84 |
| 23 | 9 | 2 | 40.48 | 43.68 | 3.20 | 4.34 | -1.14 | -0.75 |
| 24 | 9 | 4 | 38.54 | 45.14 | 6.60 | 7.35 | -0.75 | 1.89 |
| 25 | 9 | 5 | 48.57 | 25.44 | -23.13 | -19.65 | -3.48 | -1.54 |
| 26 | 4 | 9 | 37.55 | 47.13 | 9.58 | 2.62 | 6.96 | 4.21 |
| 27 | 4 | 2 | 36.48 | 46.55 | 10.07 | 10.61 | -0.54 | -3.01 |
| 28 | 4 | 4 | 34.14 | 47.65 | 13.51 | 13.61 | -0.10 | 0.99 |
| 29 | 4 | 5 | 44.43 | 32.53 | -11.90 | -13.38 | 1.49 | -15.80 |
| 30 | 12 | 9 | 43.62 | 39.20 | -4.41 | -5.36 | 0.94 | 2.33 |
| 31 | 12 | 2 | 40.59 | 42.20 | 1.60 | 2.63 | -1.03 | -1.43 |
| 32 | 12 | 4 | 37.88 | 43.96 | 6.08 | 5.64 | 0.45 | 1.09 |
| 33 | 12 | 5 | 48.03 | 22.69 | -25.34 | -21.36 | -3.98 | -0.31 |

# Appendix F: 2v2 Playoff Results – Blockage Introduced

*Table 22 – 2v2 Playoff Results - Blockage Introduced (skill weightings in Table 19)*

| ID Information | | | Attrition Information | | | | | |
|---|---|---|---|---|---|---|---|---|
| ID | Blue CtID | Red CtID | Blue Casualties | Red Casualties | Casualty Difference | Expected Difference | Difference of Difference | Compared with non-blockage |
| 1 | 3 | 22 | 44.32 | 42.53 | -1.79 | -4.51 | 2.72 | 4.06 |
| 2 | 14 | 22 | 44.12 | 35.14 | -8.98 | -14.07 | 5.09 | 4.68 |
| 3 | 20 | 23 | 47.01 | 34.61 | -12.40 | -4.65 | -7.75 | -13.88 |
| 4 | 4 | 9 | 39.51 | 46.81 | 7.30 | 6.26 | 1.04 | 16.63 |
| 5 | 16 | 9 | 44.16 | 40.03 | -4.13 | 4.60 | -8.73 | 1.02 |
| 6 | 16 | 23 | 49.27 | 26.23 | -23.05 | -15.24 | -7.81 | 0.40 |
| 7 | 14 | 23 | 41.75 | 29.81 | -11.94 | -17.14 | 5.20 | -2.53 |
| 8 | 14 | 21 | 37.65 | 46.09 | 8.44 | -0.50 | 8.94 | 10.85 |
| 9 | 10 | 19 | 36.64 | 45.95 | 9.31 | 4.46 | 4.86 | 4.07 |
| 10 | 2 | 22 | 44.45 | 43.51 | -0.94 | -0.66 | -0.29 | 2.41 |
| 11 | 2 | 7 | 41.79 | 44.69 | 2.90 | 10.75 | -7.86 | 6.14 |
| 12 | 18 | 14 | 38.40 | 42.95 | 4.54 | 13.70 | -9.16 | -3.53 |
| 13 | 14 | 10 | 46.05 | 37.85 | -8.20 | -3.20 | -5.00 | -7.35 |
| 14 | 12 | 14 | 43.16 | 40.32 | -2.85 | -4.42 | 1.57 | 0.51 |
| 15 | 12 | 16 | 45.69 | 38.65 | -7.04 | -6.31 | -0.73 | -1.05 |
| 16 | 22 | 9 | 33.44 | 49.00 | 15.57 | 16.77 | -1.21 | -8.24 |
| 17 | 9 | 23 | 49.42 | 26.64 | -22.78 | -19.84 | -2.94 | 7.13 |
| 18 | 20 | 9 | 34.87 | 47.27 | 12.39 | 15.19 | -2.80 | -8.84 |
| 19 | 10 | 22 | 36.85 | 47.74 | 10.89 | -10.87 | 21.76 | 15.70 |
| 20 | 10 | 9 | 37.54 | 48.03 | 10.49 | 5.91 | 4.58 | 24.47 |
| 21 | 12 | 20 | 49.07 | 29.28 | -19.79 | -16.90 | -2.88 | -3.74 |
| 22 | 16 | 10 | 44.88 | 39.54 | -5.34 | -1.30 | -4.04 | 1.87 |
| 23 | 4 | 7 | 37.61 | 47.50 | 9.89 | 0.90 | 8.99 | 6.48 |
| 24 | 2 | 4 | 40.84 | 45.32 | 4.48 | 9.85 | -5.37 | -0.01 |
| 25 | 2 | 3 | 41.78 | 43.89 | 2.11 | 3.85 | -1.75 | 0.81 |
| 26 | 3 | 4 | 42.22 | 44.11 | 1.89 | 6.00 | -4.11 | -0.45 |
| 27 | 2 | 12 | 29.87 | 48.92 | 19.05 | 17.83 | 1.23 | -0.29 |
| 28 | 3 | 12 | 32.09 | 47.97 | 15.88 | 13.98 | 1.91 | -0.32 |
| 29 | 12 | 4 | 46.29 | 37.61 | -8.69 | -7.98 | -0.71 | -0.32 |
| 30 | 4 | 23 | 39.75 | 44.67 | 4.92 | -13.58 | 18.49 | 6.16 |
| 31 | 2 | 23 | 48.13 | 34.66 | -13.47 | -3.73 | -9.75 | 10.76 |
| 32 | 2 | 14 | 36.04 | 43.24 | 7.20 | 13.41 | -6.21 | 3.18 |
| 33 | 2 | 20 | 40.38 | 44.94 | 4.57 | 0.92 | 3.64 | 6.77 |
| 34 | 2 | 16 | 30.82 | 49.21 | 18.39 | 11.51 | 6.88 | 0.43 |
| 35 | 2 | 9 | 34.19 | 49.07 | 14.89 | 16.12 | -1.23 | 6.01 |
| 36 | 4 | 22 | 38.79 | 46.79 | 8.00 | -10.51 | 18.51 | 14.25 |
| 37 | 4 | 14 | 41.26 | 44.22 | 2.95 | 3.56 | -0.61 | 3.92 |
| 38 | 4 | 20 | 41.93 | 41.99 | 0.06 | -8.93 | 8.99 | 0.09 |
| 39 | 16 | 4 | 43.42 | 40.13 | -3.29 | -1.66 | -1.63 | 2.37 |
| 40 | 12 | 22 | 48.76 | 28.15 | -20.62 | -18.49 | -2.13 | -0.99 |
| 41 | 12 | 23 | 49.05 | 24.56 | -24.49 | -21.55 | -2.94 | -0.36 |
| 42 | 12 | 9 | 42.25 | 42.71 | 0.46 | -1.71 | 2.17 | 0.27 |
| 43 | 22 | 24 | 36.23 | 45.62 | 9.39 | 1.20 | 8.19 | 23.67 |
| 44 | 14 | 24 | 43.90 | 36.40 | -7.49 | -12.87 | 5.38 | 12.83 |

| ID Information | | | Attrition Information | | | | | |
|---|---|---|---|---|---|---|---|---|
| ID | Blue CtID | Red CtID | Blue Casualties | Red Casualties | Casualty Difference | Expected Difference | Difference of Difference | Compared with non-blockage |
| 45 | 23 | 24 | 31.37 | 47.53 | 16.16 | 4.27 | 11.89 | 24.50 |
| 46 | 20 | 24 | 41.04 | 44.88 | 3.84 | -0.38 | 4.22 | 5.89 |
| 47 | 16 | 24 | 47.52 | 35.23 | -12.29 | -10.97 | -1.32 | 1.19 |
| 48 | 9 | 24 | 46.26 | 34.79 | -11.47 | -15.58 | 4.11 | 15.86 |

# Appendix G: MANA Movement Bug

Early in the study, when MANA Version 3.0.16 was used, a significant bias in the default scenario was noticed. Typically, the default scenario should result in, on average, mutual destruction of the forces. The bias is actually due to a bug in the MANA movement algorithm that causes the movement of entities in particular areas of the map and in particular directions to be less random than in others. Some tests were run to find out how this bug manifests itself. The results from three scenarios were compared. In each scenario the initial positions and directions of advance were changed for each side such that the lines of advance were the same as represented in Figure 14.

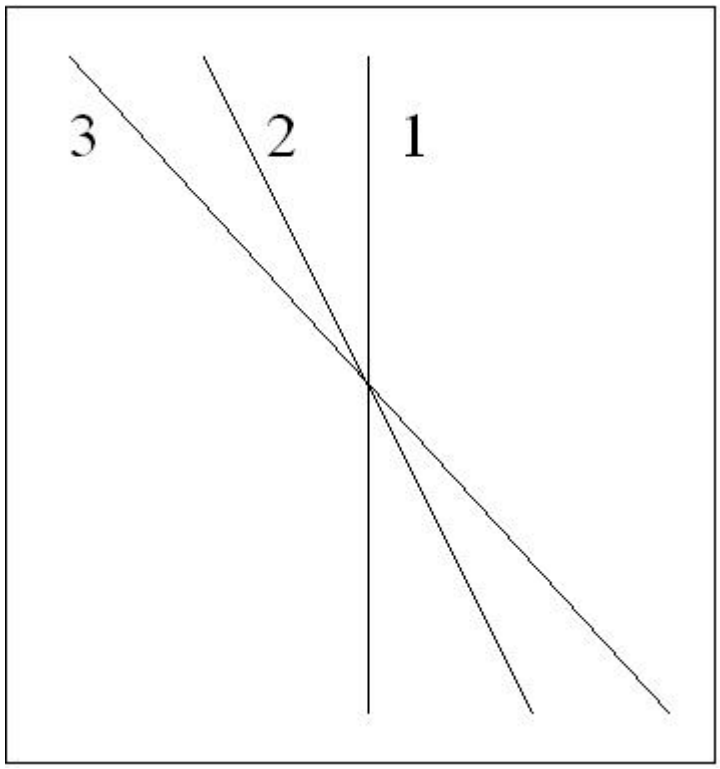


*Figure 14 - Axes of advance for test scenarios*

Scenario 1 is the same as the default scenario, scenario 2 has the sides on a 22.5 degree angle from vertical and scenario 3 has the sides approaching on the diagonal. The results are presented in Table 23. In all three scenarios the blue side starts at the bottom of the screen.

*Table 23 - Results of test scenarios*

| Scenario | Blue Attrition | Red Attrition | Casualty Difference |
|---|---|---|---|
| 1 | 37.69 | 40.37 | 2.68 |
| 2 | 34.50 | 43.60 | 9.10 |
| 3 | 27.19 | 47.92 | 20.73 |

As Table 23 shows, there is a clear disparity as the force alignment approaches the diagonal, where in fact the identical forces should suffer equal average losses. Scenario 3 showed up the probable cause of the disparity. Refer to Figure 15.

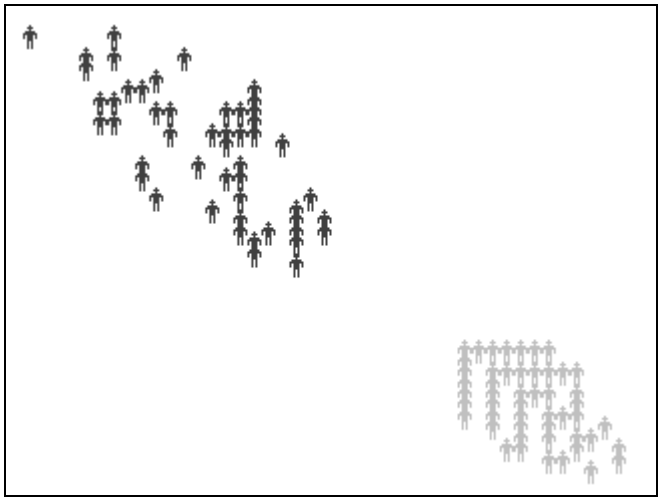

*Figure 15 - Screenshot from Scenario 3*

Figure 15 is a picture of the centre of the battlefield just as the forces are meeting. Note that the formation of the blue (light grey) side seems far more regimented and tightly packed than that of red (dark grey). This clustering of forces has the predictable effect of blue gaining advantage through localised weight of numbers. It is unknown at this point exactly what causes this problem, but several things have been deduced.

Given the nature of the default movement algorithm in MANA all units should be moving with some randomness, but generally towards the intended direction. The blue units in the above picture are picking the 'best' move in their movement algorithm more often than red. Also, this problem is weighted towards the bottom right of the battlefield. As shown by the scenarios played out above, the closer a force starts to the bottom right hand corner, the more effective it is.

This bug is present in MANA v3.0.16 and was fixed by v3.0.34 onwards. It did not affect this study but has potential to invalidate results by anyone using a bugged version of MANA.

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The agent based distillation MANA was used for a parametric study of the seven core skills of the Army-as-a-system model, using a bottom-up approach. Simple tactics were developed, then combined, so more complex behaviour emerged. Scenarios in which base and combined tactics were played against each were used to measure the effectiveness of various combinations of core skills. Preliminary results indicate that the complex adaptive behaviour displayed by the simulation entities led to multiple distinct end-states. In addition, a 'rock-scissors-paper' paradigm emerged between combinations of tactics, where a cyclic, rather than linear, relationship was observed for the capacity of pairs of tactics to perform well against one another.